PB85-111334

Nationwide Urban Runoff Program, Fresno, California: Final Report

Fresno Metropolitan Flood Control District, CA

Prepared for

Environmental Protection Agency, Washington, DC

May 84

U.S. Department of Commerce
National Technical Information Service
NTIS

50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO.

2.

3. Recipient's Accession No. PB85 111334

4. Title and Subtitle
Nationwide Urban Runoff Program, Fresno, CA, FINAL REPORT.

5. Report Date May, 1984

6.

7. Author(s)
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8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Fresno Metropolitan Flood Control District
City of Fresno, CA

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G) P009321-01-0

12. Sponsoring Organization Name and Address
EPA, Office of Water Program Operations
Water Planning Division
401 M Street, SW
Washington, D C 20460

13. Type of Report & Period Covered
Final, 1980-1984

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This report documents the environmental impacts of the practice of retention and recharge of urban storm runoff through the existing system of retention/recharge basins. Since drinking water is obtained from groundwater sources, and the turfed recharge basins are used during summer months for recreation, the possibility of potential impacts resulting from pollution was a concern.

17. Document Analysis a. Descriptors

Hydrology
Urban development
Watersheds
Water pollution
Water resources
Sedimentation
Storms
Regional planning
Urban planning
Civil Engineering

b. Identifiers/Open-Ended Terms
Runoff
Streamflow
Stream pollution
Rainfall
Snowmelt
Soil Erosion
Water Quality
Sediments
Sediment Transport
Suspended Solids
Storm Drains
Urbanization
Land use

c. COSATI Field/Group

18. Availability Statement: No restriction on distribution. Available from National Technical Information Service, Springfield, VA 22161

19. Security Class (This Report) UNCLASSIFIED

20. Security Class (This Page) UNCLASSIFIED

21. No. of Pages 172

22. Price

(See ANSI-Z39.18)

See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

PB85-111334

FRESNO NATIONWIDE URBAN RUNOFF PROGRAM PROJECT

FRESNO METROPOLITAN FLOOD CONTROL DISTRICT

FINAL REPORT

MAY 1984

BC BROWN AND CALDWELL

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May 11, 1984

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Subject: Final Report for Fresno Nationwide
Urban Runoff Program Project

Dear Mr. Harrison:

We are pleased to submit the final report for the Fresno Nationwide Urban Runoff Program (NURP) project. This report provides a comprehensive documentation of the work conducted on this project over the past three years. For convenience, Chapter 1 is a summary of the key findings of each of the report chapters. A set of specific management practices to improve the current operation of the retention/recharge system is presented in Chapter 9. These recommendations incorporate the suggestions made by the project team and the technical and citizen committees at our review meetings on April 24, 1984.

We have thoroughly enjoyed participating in the Fresno NURP project. Its success can in large part be attributed to the team approach that has been followed since the outset of the project. We thank you and the other District staff, including Bob Van Wyk and Jerry Lakeman for your guidance and support. The excellent work performed by Rick Oltmann of the U.S. Geological Survey and Harry Nightingale of the U.S. Department of Agriculture form the technical foundation for the final report. The other key individuals who have contributed to the project are identified in the listing following this letter.

Very truly yours,

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CHAPTER 1

SUMMARY

In a report of this magnitude, a summary is essential to provide an overview of the study and its findings. The following sections briefly describe the important points of each chapter of the report.

INTRODUCTION

This study is part of the Nationwide Urban Runoff Program (NURP) initiated by the U.S. Environmental Protection Agency (EPA) in 1978. The Fresno project is one of 28 projects being conducted at locations across the country. The primary objectives of NURP are to determine to what extent urban runoff is contributing to water quality problems and to evaluate various management practices for controlling urban runoff.

The Fresno project was selected as one of the NURP projects for three main reasons. First, the receiving water for urban runoff in the Fresno-Clovis area is the groundwater. Only one other NURP project (Long Island, New York) is addressing impacts on groundwater. Secondly, the Fresno groundwater supply is a sole source aquifer, and the potential for degradation is a matter of significant importance to the local community. Third, the Fresno project can demonstrate the effectiveness of a specific best management practice, i.e., the total retention and recharge of urban storm runoff.

OBJECTIVES AND APPROACH

The Fresno Metropolitan Flood Control District (District) has developed a system of retention/recharge basins to handle runoff during storm periods. The system has a dual purpose: it services urban drainage needs and at the same time recharges the groundwater aquifer. The District currently has a total of 86 recharge basins of which 74 are completed or are in various stages of excavation. These basins have a total area of over 1,000 acres.

The participation of the District in NURP was initiated at the request of the District because of the recognition that urban storm runoff recharged to the groundwater represented a potential source of pollution. Thus, the major objective of the

Fresno NURP project is to determine the environmental impacts of the current practice of retention and recharge of urban storm runoff. The two areas of specific concern are potential impacts on the quality of drinking water which is obtained from the groundwater supply, and recreation, which is permitted during the summer months in the turfed recharge basins.

This project has been conducted over a three-year period. The project was fully authorized in early 1981, and the bulk of the field work was completed in the fall of 1983. The District has utilized three subcontractors. The U.S. Geological Survey (USGS) has conducted the runoff monitoring program. The Water Management Research Unit of the U.S. Department of Agriculture (USDA) conducted the soils and groundwater monitoring program. Brown and Caldwell has been responsible for preparation of the interim and final reports and conducted portions of the laboratory work.

RUNOFF MONITORING PROGRAM

The USGS collected extensive data on the quantity and quality of storm runoff and rainfall and on the quality of dry deposition and street particulate material. Samples were collected from a total of 27 storms over the two-year monitoring program. Runoff samples were collected from four land use types: single-family residential, multiple-family residential, commercial, and industrial. Samples were analyzed for a wide array of constituents, including nutrients, solids, major ions, metals, and pesticides.

The runoff results indicated that urban runoff contains significant levels of many contaminants, including most heavy metals and some organic compounds. Constituents which have runoff concentrations significantly higher than the regional groundwater include lead, zinc, copper, mercury, iron, and manganese. In contrast, runoff is better in quality than the regional groundwater from the standpoint of minerals and nutrients. Rainfall samples contained 14 organic compounds, including 11 pesticides.

Comparison of the runoff data for the four land use types showed that the industrial area had the worst runoff quality. Concentrations in the industrial runoff fluctuated greatly during storms, and numerous unexplained concentration spikes were monitored. Runoff concentrations over the course of a storm event at the non-industrial sites followed the traditional "first flush" concept. The highest concentrations for most constituents occurred during the initial storm runoff and then decreased throughout the remainder of the storm. Contaminant concentrations were also generally highest for the first two or three storms of the year and fairly constant thereafter.

SOILS AND GROUNDWATER MONITORING PROGRAM

The USDA field program consisted of sampling of four major components: soils, soil water, groundwater, and plant tissue. Five of the District's recharge basins were monitored: three turfed basins and two unturfed basins that receive imported surface water for recharge during the summer. Several sets of soil samples were collected between the summer of 1981 and the fall of 1983. Water samples were collected first on a bimonthly then on a monthly basis between January 1982 and July 1983. Water samples were collected from the unsaturated zone and at top of the water table underlying each test basin using vacuum soil water extractors.

Soil results showed that the soils in the recharge basins provide a high degree of removal of storm runoff contaminants, thereby protecting groundwater quality. Although there is some evidence of downward movement of some contaminants in the soil, no contamination of the soil water or groundwater has occurred in any of the five basins studied.

Lead and chlordane were the most commonly found contaminants in the surface soils. Lead is a component of gasoline, brake linings, and rubber tires. Chlordane was first introduced as an agricultural pesticide, but currently its use is restricted to subterranean termite control. The surface distribution of lead was determined through a spatial survey of two recharge basins. The highest concentrations of lead occurred at low spots in the basin and close to the basins outfalls.

The recharge of imported irrigation water appears to have a beneficial impact on groundwater quality, although some leaching of basin soils is occurring. There appears to be a correlation between the degree of removal of metals and the proportion of silt plus clay and organic matter in the surface soils.

SYSTEM ANALYSIS

The data collected in the two main elements of the program (USGS runoff monitoring and USDA soils and groundwater monitoring) were integrated, so that pollutants could be traced through the entire system from rainfall to regional groundwater. The system components included rainfall, dry deposition, street particulate material, runoff, basin soils, soil water, and groundwater. Results for lead, specific conductance, calcium, and nitrate were analyzed to demonstrate changes that occur in the runoff/recharge system for different types of constituents.

For example, lead concentrations were fairly low in rainfall and quite high in runoff, indicating lead comes primarily from ground sources. Lead concentrations in the soil water and groundwater underlying the recharge basins were very comparable to background levels found in the regional groundwater. This shows that the soil layer is an excellent mechanism for removing the lead from the percolating runoff water.

A loading analysis was performed to determine if the pollutant loads can be correlated with the amounts of the pollutants present in the basin soils. Although several variables could not be quantified in the loading analysis, the comparison of runoff loads with soils loads provided some general insights. In most cases, the runoff loads corresponded reasonably well to the soil loads. Although in a few cases the data imply that there may be some loss of lead and other constituents from the basin soils to the groundwater, no increase in constituent levels were observed in the groundwater measurements.

IMPACTS OF RUNOFF ON WATER SUPPLY AND RECREATION

The two areas of primary concern in our evaluation of recharge impacts are water supply and recreation. The groundwater to which storm runoff is being recharged is the drinking water supply for the Fresno area. In addition, 13 of the District's recharge basins are turfed and are used for various forms of recreation during the late spring and summer months. The key findings related to these two primary areas of concern are listed below.

1. Water Supply Impacts--Currently, there are no apparent adverse impacts on the groundwater resulting from recharge of urban storm runoff. Of the metals and organic compounds tested, concentrations in the soil water and groundwater underlying the five test basins are well within the drinking water standards established by the Safe Drinking Water Act. Two of the basins tested have been in operation for over 20 years. It is unlikely that continued recharge to basins similar to those tested in this program will cause adverse impacts on the groundwater in the near future. Continued monitoring of the groundwater underlying the recharge basins would detect changes in groundwater quality well in advance of a problem occurring.

   However, one situation where storm recharge could pose a potential threat to the groundwater was not evaluated in this program: a basin serving an area that has a significant amount of industrial development.

We are recommending that additional monitoring be conducted to cover this particular situation.

2. Recreation Impacts--Lead levels, and to a lesser extent chlordane levels, in the surface soils of localized areas in some of the recharge basins exceed the California Department of Health Services (DHS) soil criteria. The primary public health concern for lead is ingestion of soil. The opportunity for soil ingestion in the District's recreational basins is limited, since the recreational basins are entirely turfed with the exception of the baseball diamonds in three basins. These violations of the soil criteria are of concern, but appear to be manageable through management practices. The impact of inhalation of dust particles containing lead was preliminarily assessed and this does not appear to be a problem based on comparison with the lead criterion for worker exposure.

   Although there are no identified health problems associated with current basin operation, the potential for future impacts does exist. Thus, the District should continue to manage and operate the basins in a manner that minimizes the risk to both groundwater quality and recreation.

BEST MANAGEMENT PRACTICES

The current operation of the District's retention/recharge system is the best management practice for stormwater management that has been the focus of this study. The results show that the current system is basically a sound methodology for meeting its two goals: stormwater management and recharge of the groundwater supply. The fact that the system has operated successfully with proven water quality and recreation benefits for over 20 years is a credit to the original design concept.

Since our analysis indicated that there is some potential for future impacts, certain modifications to the District's current procedures are warranted to insure a future which continues to be free of adverse impacts. Basin management practices that have been considered include: providing additional low-flow basins, removing basin soils, modifying pumpout methods, turfing unturfed areas, and long-term monitoring. Two source control measures have also been evaluated: street sweeping and upstream controls at industrial areas.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions from the Fresno NURP project and specific recommendations to improve the retention/recharge system operation are delineated in Chapter 9. Most of the key conclusions have been cited in the previous sections of this summary. Specific recommended management practices are summarized in Table 1-1.

Table 1-1. Recommended Management Practices

1. Maintain the basic practice of retention and recharge of urban storm runoff subject to certain modifications.

2.[a] Provide low-flow basins for all recreational basins and evaluate low-flow basins for basins serving industrial areas. Periodically remove solids from the bottom of low-flow basins and from basins serving principally industrial areas.

3.[a] Remove the portion of the turf and upper soil layer from the recreational basins as necessary.

4.[a] Monitor soil from unturfed areas in recreational basins and remove as necessary.

5. Consider having industrial developments contain or pretreat runoff from portions of their site that may contain toxic material.

6. Have the District work together with other local agencies to be certain that water quality aspects are adequately considered in the review process for future industrial developments.

7. Develop a management plan to determine the best means of disposing of hazardous soil removed from the basins.

8. Continue the practice of recharging high quality imported surface water.

9. Implement a long-term monitoring program of basin soils and groundwater.

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[a] The need for soil removal should be based on further soils monitoring and contaminant buildup curves relative to public contact and drinking water standards.

The recommended practices listed in Table 1-1 involve physical improvements to some basins, additional operational measures, and changes in District policy. In the case of some of the recommendations, a detailed course of action cannot be implemented without further research or engineering. Such additional engineering and research needs include: a detailed determination of soil conditions in the recreational basins, a determination of specific runoff quality from existing industrial sites, and a determination of the quality and downstream impacts of runoff water pumped from recharge basins into the irrigation canals. It is also recommended that an evaluation of the engineering design standards for all future storm drainage retention basins be performed. Ongoing monitoring work is recommended in order to develop a continuing record of soil and groundwater conditions, to evaluate some situations not covered by this project, and to assess the effectiveness of recommended control measures.

CHAPTER 2

INTRODUCTION

The urban runoff study being conducted in Fresno County is part of the Nationwide Urban Runoff Program (NURP). This chapter describes the study area, purpose and scope of NURP, the selection of Fresno as one of the projects, initial planning for the Fresno NURP project, and the organization of this report.

STUDY AREA

This study deals with recharge of stormwater runoff in the Fresno-Clovis metropolitan area of Fresno County, California. The Fresno-Clovis area is located about 160 miles southeast of San Francisco and lies within the highly agricultural San Joaquin Valley (Figure 2-1). The study area contains over 166 square miles and includes a population of about 350,000 people.

Climate

Within the study area, the climate is generally mild and stable. Summers are hot and dry, while winter is marked by moderate temperatures and relatively light precipitation. The warmest daytime highs occur in July and pass 100 degrees F., but fall quickly to night lows of 65 degrees F. Major wind movement follows the major axis of the valley from northwest to southeast and humidity is low. The winter temperatures are mild between infrequent cold periods. The coldest days usually occur in December and January with the normal maximum over 50 degrees F. and the normal minimums at 35 degrees F.

The study area is subject to winter storms that move on shore from Pacific low pressure systems, dropping rain in the valley and generous amounts of snow at higher elevations in the Sierra Nevada. The Coast Range insulates the valley from the major effects of the Pacific Ocean. The rainfall in the valley decreases from north to south. The average annual rainfall in the study area is about ten inches, falling primarily between October and April.

Geology, Topography & Soils

The geological composition of the area is characteristic of the San Joaquin Valley, being comprised of recent aluvium fans formed by sediment deposition from streams flowing from the Sierra Nevada mountains. The vast majority of the geologic environment consists of materials of granitic origin. Both young and old granitic alluvium, as well as granitic parent rock are found. The young alluvium generally consists of deep deposits of silts and sands, while the older deposits are comprised of consolidated and cemented substratums.

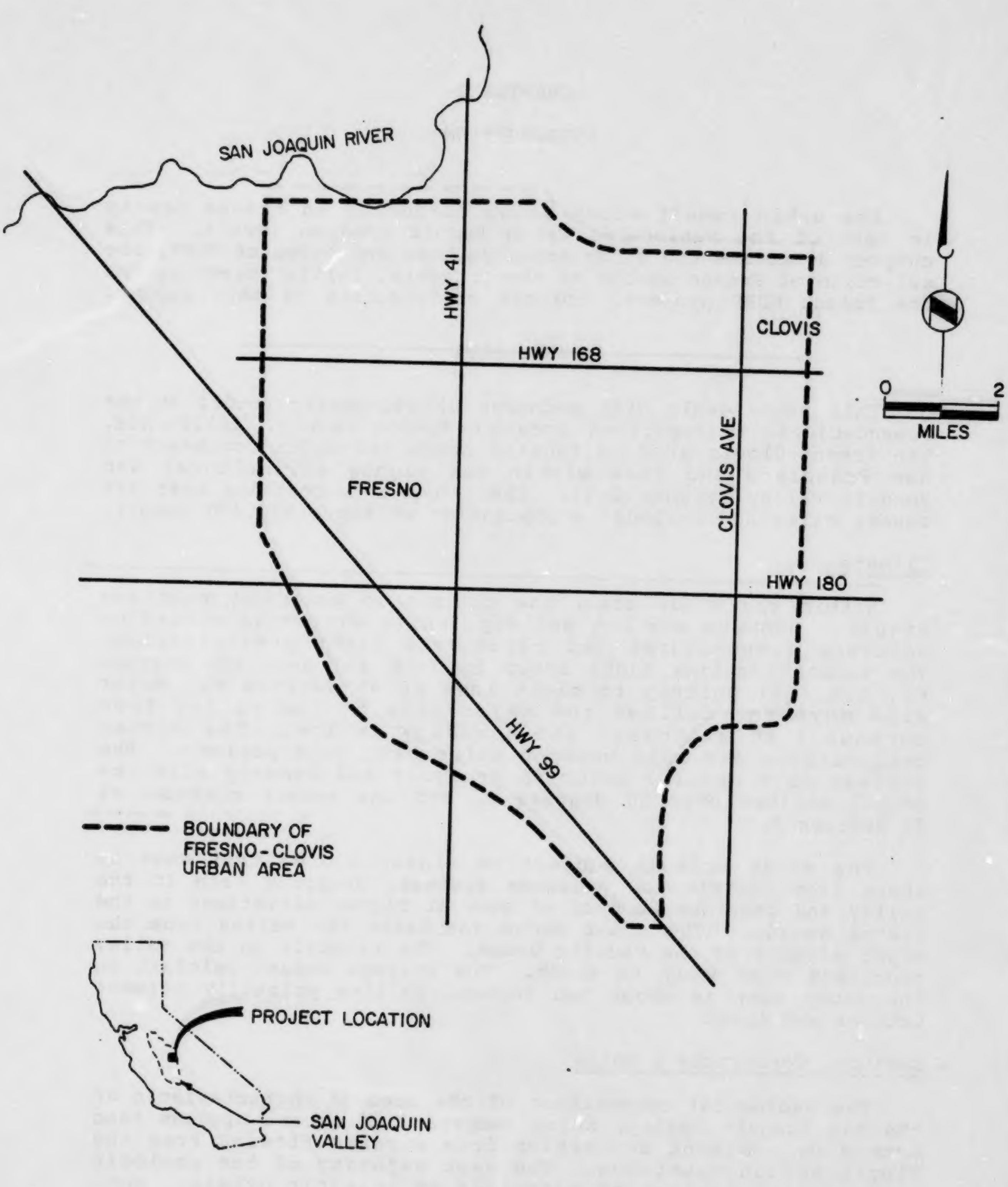


Figure 2-1 Location Map

The topography of the study area is similar to the balance of the San Joaquin Valley, essentially flat with no distinguishable land forms. Only slight changes in elevations occur across the entire study area. Older alluvial terraces east of Fresno develop an undulating relief of rounded hills; while the granitic and metamorphic rocks of the Sierra Nevada foothills develop moderate to steep slopes.

The soils of Fresno County are noted for being among the richest and most productive in the world. Soil types which occur in the vicinity of the study area are generally level, well drained and have a surface layer of loam or sandy loam.

Hydrology and Water Supply

The study area is traversed by several low-elevation streams which drain a portion of the western slope of the Sierra Nevada mountains. The drainage basins of these streams lie between the San Joaquin River on the north and the Kings River on the south. Streamflow in these low-elevation streams is at a very low level during the summer months and increases in the late fall in response to precipitation.

Although surface water (from the Kings and San Joaquin Rivers) is used to meet some of the agricultural water needs of the region, potable water for the metropolitan area is obtained exclusively from groundwater underlying the area. There are hundreds of wells operated by various water purveyors in the area. The aquifer covering the study area is part of the much larger Tulare Lake Basin. Groundwater generally flows from the northeast to the southwest with a large cone of depression in the central area. The water table has gradually dropped over time due to the high degree of groundwater pumping. In 1978, the depth to groundwater ranged from about 40 feet in the southern portion of the urban area to more than 110 feet in the northern portion of the urban area.

The recharge occurring in the storm runoff retention basins serves an important role in mitigating the groundwater overdraft. The basins are used to replenish the groundwater supply through the retention and recharge of the storm runoff itself and through the recharge of high quality imported surface waters delivered to the basins through connections to the irrigation canal system. The use of the basins has become a major water supply management practice which will be expanded as facilities become available as the community continues to grow.

NATIONWIDE URBAN RUNOFF PROGRAM

The water quality effects of nonpoint sources in general, and urban runoff in particular, were recognized by PL 92-500, the Water Pollution Control Act Amendments of 1972. An assessment of urban runoff was included as a study element in 93 of the Section 208 Areawide Waste Management Plans being conducted across the nation. In 1978, the U.S. Environmental Protection Agency (EPA) reviewed the results of these 208 urban runoff evaluations and determined that additional, consistent data were needed to obtain an adequate understanding of the pollution effects of urban runoff. In response, EPA initiated NURP to build upon pertinent prior work, to provide additional practical information and to create a basis for future policy and program development and implementation. The five-year program is intended to answer three broad questions:

1. To what extent is urban runoff a contributor to water quality problems across the nation?
2. What is the effectiveness of controls, short of treatment, in reducing water quality problems where they exist?
3. Are best management practices for control of urban runoff cost-effective in comparison to alternative options?

NURP consists of 28 projects at locations distributed throughout the country (Table 2-1). It represents a federal commitment of nearly $20 million, together with local resources amounting to an additional $7.5 million. The NURP projects are being managed by either state, county, city, or regional governments. The Water Planning Division of EPA in Washington, D.C. has coordination responsibility for the individual projects and provides technical assistance. EPA is utilizing the data from the projects to prepare a national assessment of urban runoff. EPA completed a final draft of their final report in September 1983.

Table 2-1. Nationwide Urban Runoff Program Project Locations

1. Durham, New Hampshire
2. Lake Quinsigamond, Massachusetts
3. Mystic River, Massachusetts
4. Long Island, New York
5. Lake George, New York
6. Irondequoit Bay, New York
7. Metro Washington, D.C.
8. Baltimore, Maryland
9. Myrtle Beach, South Carolina
10. Winston-Salem, North Carolina
11. Tampa, Florida
12. Knoxville, Tennessee
13. Lansing, Michigan
14. Oakland County, Michigan
15. Ann Arbor, Michigan
16. Champaign-Urbana, Illinois
17. Chicago, Illinois
18. Milawukee, Wisconsin
19. Austin, Texas
20. Little Rock, Arkansas
21. Kansas City, Kansas
22. Denver, Colorado
23. Salt Lake City, Utah
24. Rapid City, South Dakota
25. Castro Valley, California
26. Fresno, California
27. Bellevue, Washington
28. Eugene, Oregon

PROJECT SELECTION

NURP projects were selected from among the original 93 areawide agencies that had identified urban runoff as one of their significant problems. The selection criteria used to screen the agencies included: existence of a water quality problem, type of receiving water, hydrologic characteristics, urban characteristics, and beneficial use of the receiving water. An effort was made to select projects which collectively represented a wide range of characteristics. EPA utilized a matrix analysis to be sure that all of the major types of urban runoff situations were covered by at least one project.

The Fresno-Clovis metropolitan area was selected as one of the NURP projects for several reasons:

1. The receiving water for urban runoff in the Fresno-Clovis area is the groundwater. Only one other NURP project (Long Island, New York) is addressing impacts on groundwater.
2. The groundwater reservoir underlying the Fresno-Clovis area has been designated by EPA as a sole source aquifer. The potential for degradation of such a reservoir is a matter of significant importance to the local community.
3. The Fresno project can demonstrate the effectiveness of a specific best management practice, i.e., the total retention and recharge of urban storm runoff. This practice has potential application in a number of other locations. For example, many communities rely on groundwater as the principal source of their drinking water supply. Data from the Fresno project will be directly applicable to those communities who are considering or practicing retention and recharge of urban runoff.

INITIAL PLANNING

Because of the sole reliance on groundwater as a water supply for the Fresno-Clovis area, water quality protection has been an important matter for local authorities. Groundwater-related issues have been the subject of a number of studies.

The 208 Water Management Plan for the Fresno-Clovis area evaluated water quantity and water quality issues. The plan identified some existing groundwater quality problems in specific areas, including high nitrate, hardness, salinity, and chloride levels. A number of potential pollution sources were also identified: industrial wastes, septic tanks, agricultural nonpoint sources, and storm runoff. Storm runoff was included as a potential pollution source because by design, virtually all storm runoff in the metropolitan area is recharged to the groundwater aquifer. There are no significant watercourses passing through the area to which storm runoff can be discharged. Thus, the Fresno Metropolitan Flood Control District (District) has developed a system of retention/recharge basins to handle runoff during storm periods. Presently, there are over 1,000 acres of basins. Trace elements and organic chemicals were considered to be the largest sources of pollution in storm runoff. Although domestic supply wells in the urban area had generally shown no noticeable impact resulting from recharge of urban storm runoff, the 208 plan indicated that there was a need for more comprehensive monitoring in the vicinity of the recharge basins. More specifically, the Interim Best Management Plan of June 1979 recommended that the District develop a monitoring program to determine the impact of stormwater recharge on groundwater.

Detailed planning for a monitoring program was initiated in mid-1979. Discussions were held with EPA officials about including such a study for Fresno in NURP. With assistance from various water quality experts, the District prepared a work plan entitled "Determination of Potential Adverse Environmental Impacts Associated with the Retention and Recharge of Urban Storm Runoff". The work plan was originally submitted to EPA and the State Water Resources Control Board (State Board) in October 1979 and was revised in November 1979. EPA conditionally approved the work plan in December 1979, subject to certain modifications to the proposed program. A 208 grant of $796,000 was authorized for the three-year study.

Data gathering was scheduled to begin in the fall of 1980. However, due to the late entry of the State of California into the project, the time required to prepare and execute contracts, make funding arrangements, and refine work plans to the satisfaction of all participants was much greater than anticipated. The transfer of the 208 program authority from EPA to the State Board further complicated contract arrangements. The Technical Advisory Resource Group met in March and October 1980 to review the work plan and to discuss monitoring program details such as sampling sites and procedures. The master contract among the State Board, County of Fresno, and the District, and the individual contracts between the District, the U.S. Department of Agriculture (USDA) and the U.S. Geological Survey (USGS), were not executed until the spring of 1981, although these contracts were all technically effective October 31, 1980.

Because of the time needed to finalize contract arrangements and the subsequent time needed to obtain and calibrate equipment, the monitoring program was delayed about one year from the original work plan. USDA began their monitoring work in July 1981 and USGS initiated monitoring in October 1981. The delays in initiating the monitoring program created corresponding delays throughout the entire project, although efforts were continually made to complete the project within the "contract limits". The schedule of the various elements included in the monitoring program is contained in Chapter 3.

REPORT ORGANIZATION

The Fresno NURP project has had extensive reporting requirements. A series of 12 quarterly reports were prepared over the course of the project. The quarterly reports summarized work progress to date, provided preliminary conclusions, identified problems, and compiled data. Two annual reports were prepared. The First Annual Report (October 1982) served primarily as a vehicle for defining changes in the study design for the second year of monitoring and for reporting early runoff quality data. The Second Annual Report (September 1983) summarized most of the data collected in the monitoring program and made an initial assessment of the impacts of recharging urban runoff.

Both USGS and USDA have prepared individual project reports covering their portion of the study. USDA and USGS issued their draft reports in September 1983 and November 1983, respectively. These reports, together with supporting appendices, contain the complete data tabulations and statistical analysis for the project.

This final report for the Fresno NURP project is intended to be a comprehensive report in that it contains the key features of the previous reports. However, because of the large amount of data collected in this program, data are generally presented in summary form in this report. For example, maximum, minimum, and median values are often reported for a particular data set rather than tabulating individual data points. The complete data tabulation is contained in the USGS and USDA final reports, appendices, and quarterly reports. In addition, most of the USGS data can be accessed from WATSTORE, their data management system.

This final report contains a total of nine chapters. Chapter 1 is a summary of the key points of each of the following chapters. Chapter 2 provides background information on the project, and Chapter 3 describes the project objectives and approach. The results of the USGS runoff monitoring program and the USDA soils and groundwater monitoring program are contained in Chapters 4 and 5, respectively. Chapter 6 is a system overview of the key results from the USGS and USDA programs. Chapter 7 is an assessment of the impacts of recharging urban storm runoff. Chapter 8 analyzes various management practices that can be implemented to minimize adverse environmental impacts. Specific conclusions and recommendations are identified in Chapter 9.

CHAPTER 3

OBJECTIVES AND APPROACH

The work plan for the Fresno Nationwide Urban Runoff Program (NURP) project (October 1979) set forth the objectives and general approach for the study. These objectives and the specific tasks required to meet these objectives have subsequently been refined and described in more detail by the Fresno Metropolitan Flood Control District (District) staff and their subcontractors. This chapter presents the objectives, organization, scope of work, and schedule for the Fresno NURP project. A brief description of the District's retention/recharge system is initially presented so the objectives of the project can be beter understood.

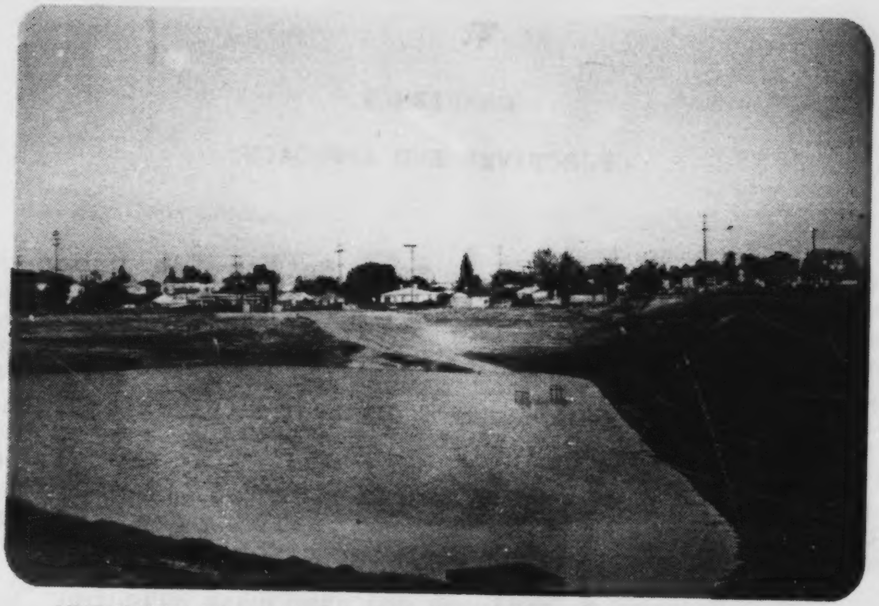
RETENTION/RECHARGE SYSTEM

Stormwater management in the Fresno metropolitan area is complicated by the fact that there are no significant watercourses passing through the area to which storm runoff can be discharged. Therefore, the District has developed a system of retention/recharge basins to handle runoff during storm periods. The system has a dual-purpose: it serves urban drainage needs and at the same time recharges the groundwater aquifer, which is the sole water supply for the region.

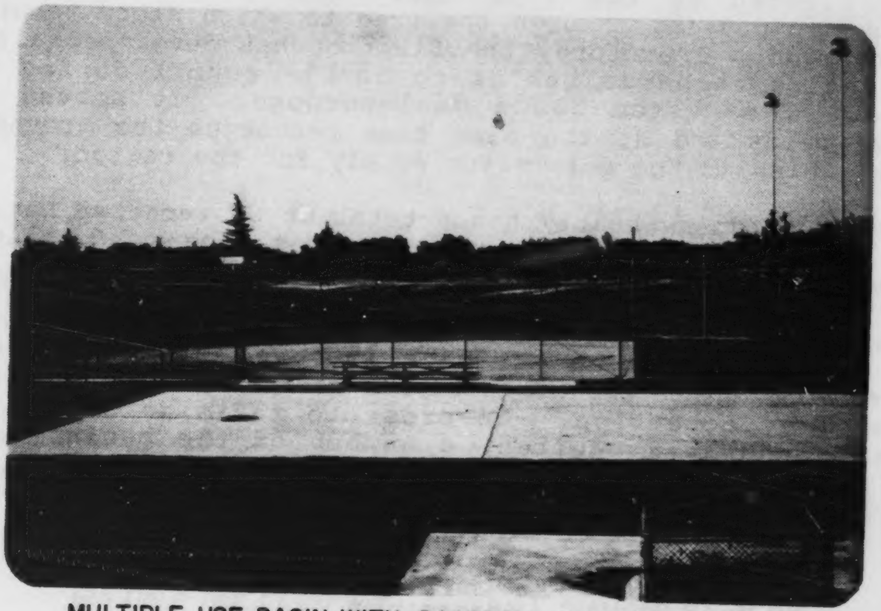
The District currently has a total of 86 recharge basins of which 74 are completed or are in various stages of excavation (Figure 3-1). The basins have a total area of over 1,000 acres. Fourteen of the basins are turfed or partially turfed, with 13 of these used for recreation during the dry weather season. Three of the turfed basins have improved baseball diamonds (Figure 3-1), while the other turfed basins are used for soccer and passive recreation. In order to maximize the recharge of the groundwater aquifer, a number of the basins receive irrigation water for recharge during the summer. Irrigation water is diverted into these basins from the canal system that passes through the Fresno area.

OBJECTIVES

The Fresno NURP project was developed because of the District's recognition that urban storm runoff recharged to the groundwater represented a potential source of pollution. Thus,



UNTURFED BASIN USED FOR RECHARGE OF STORM RUNOFF AND IMPORTED SURFACE WATER BASIN EE



MULTIPLE USE BASIN WITH BASEBALL DIAMOND BASIN B/E

Figure 3-1 Photographs of Recharge Basins

the major objective of the project is to determine the environmental impacts of the current practice of retention and recharge of urban storm runoff. The subobjectives of the project are described below and their interrelationships are graphically shown on Figure 3-2.

The first subobjective is to characterize the chemical composition of runoff, soils, and groundwater. Before any conclusions can be drawn about the potential impacts of recharge, the water quality of the urban runoff that occurs during storm events must be clearly defined. The physical and chemical properties of the runoff have been evaluated, with particular emphasis on toxic pollutants, such as metals and pesticides. The runoff percolates down through the soils and eventually reaches the water table which is generally located about 100 feet below the ground surface. Some compounds are altered or partially removed as a result of various physical, chemical, and biochemical processes occurring in the soil. Thus, it is necessary to determine the chemistry of the soils, as well as the quality of the water located in the unsaturated zone above the water table. Finally, measurements need to be made of the groundwater itself.

The second subobjective is to determine whether there is currently or there is a future potential for adverse impacts associated with the recharge of urban runoff. The primary issue of concern is protection of the area's groundwater supply. A secondary concern is the potential for impacts on recreational use that occurs in some of the recharge basins during non-winter periods: for example, does a potential hazard exist when dust is stirred up on the basin baseball diamonds and is inhaled or when basin soil is ingested by a child?

The third subobjective is to identify and evaluate management practices that can be used to alleviate adverse impacts, if any are found to exist. Management practices will fall into two categories:

1. Changes in the way the recharge basins are designed and operated to minimize impacts.

2. Source controls to change the quality of runoff before it reaches the basins.

ORGANIZATION

Several organizations have been involved in the Fresno NURP project (Figure 3-3). The project is part of a nationwide program initiated by the U.S. Environmental Protection Agency (EPA). EPA has provided a 208 grant, which is one of the

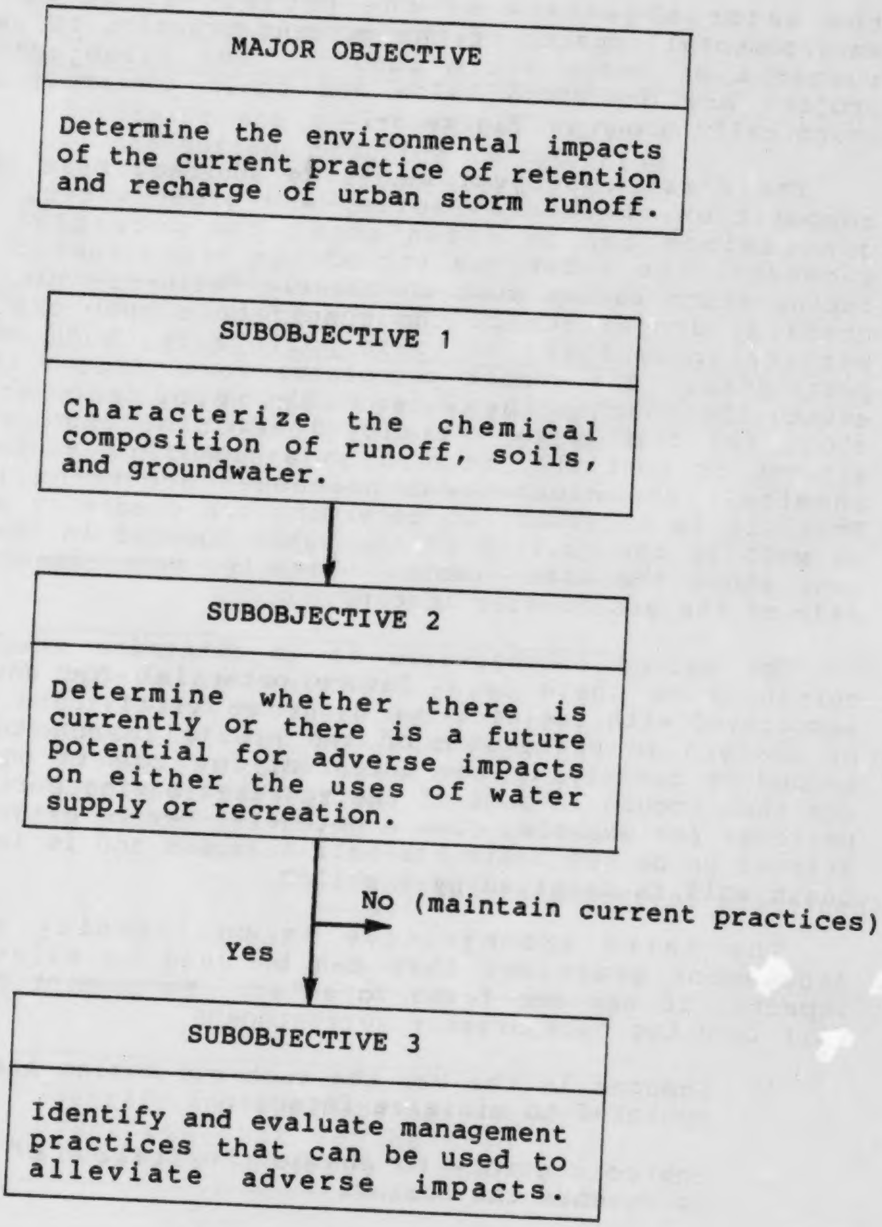

MAJOR OBJECTIVE
Determine the environmental impacts of the current practice of retention and recharge of urban storm runoff.
SUBOBJECTIVE 1
Characterize the chemical composition of runoff, soils, and groundwater.
SUBOBJECTIVE 2
Determine whether there is currently or there is a future potential for adverse impacts on either the uses of water supply or recreation.
No (maintain current practices)
Yes
SUBOBJECTIVE 3
Identify and evaluate management practices that can be used to alleviate adverse impacts.

Figure 3-2. Objectives of Fresno Nationwide Urban Runoff Program Project

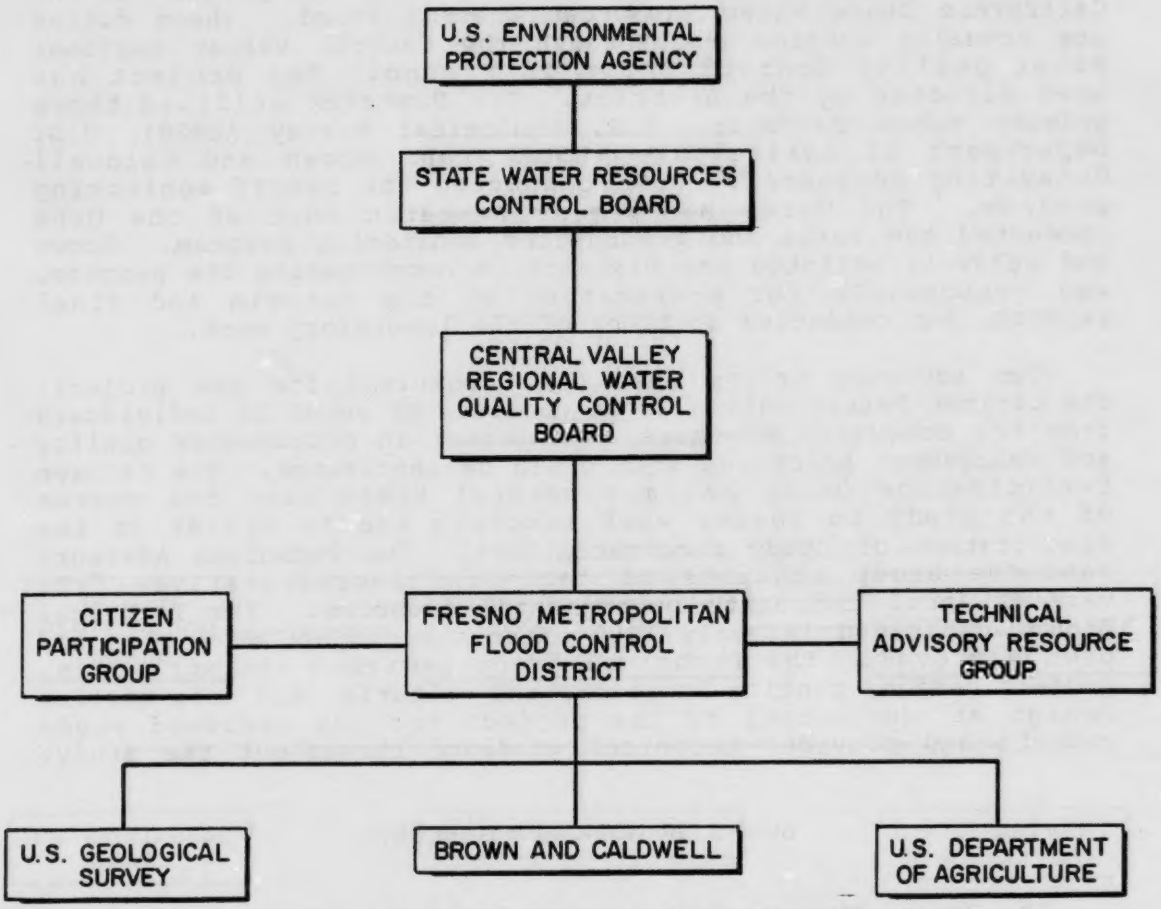

U.S. ENVIRONMENTAL PROTECTION AGENCY
STATE WATER RESOURCES CONTROL BOARD
CENTRAL VALLEY REGIONAL WATER QUALITY CONTROL BOARD
CITIZEN PARTICIPATION GROUP
FRESNO METROPOLITAN FLOOD CONTROL DISTRICT
TECHNICAL ADVISORY RESOURCE GROUP
U.S. GEOLOGICAL SURVEY
BROWN AND CALDWELL
U.S. DEPARTMENT OF AGRICULTURE

Figure 3-3 Organization Chart for Fresno NURP Project

primary sources of funding for the study. The District provided the remainder of the direct funding, and in-kind services were provided by several other agencies. EPA has delegated contract administration responsibilities for the project to the California State Water Resources Control Board. These duties are actually carried out through the Central Valley Regional Water Quality Control Board in Fresno. The project has been directed by the District. The District utilized three primary subcontractors: U.S. Geological Survey (USGS), U.S. Department of Agriculture (USDA), and Brown and Caldwell Consulting Engineers. USGS conducted the runoff monitoring program. The Water Management Research Unit of the USDA conducted the soils and groundwater monitoring program. Brown and Caldwell assisted the District in coordinating the program, was responsible for preparation of the interim and final reports, and conducted portions of the laboratory work.

Two advisory groups have been organized for the project. The Citizen Participation Group consists of about 20 individuals from the community who have an interest in groundwater quality and management practices that could be instituted. The Citizen Participation Group has met several times over the course of the study to review work progress and to assist in the finalization of study recommendations. The Technical Advisory Resource Group consists of technical representatives from various local and state governmental agencies. The Technical Group was formed in early 1980 after the project work plan had been approved. The Technical Group reviewed the work plan, project design, testing locations and criteria, and data station design at the outset of the project and has reviewed study reports and provided technical guidance throughout the study.

SCOPE OF WORK AND SCHEDULE

The Fresno NURP project has been conducted over a three-year period. The project was fully authorized in early 1981, and the bulk of the field work was completed in the fall of 1983. Major elements of the project and their individual schedules are shown on Figure 3-4 and are briefly described below.

U.S. Geological Survey Work

The main objective of the USGS work was to characterize the quality of urban storm runoff from various land uses. USGS conducted all of the aboveground sampling, which consisted of samples of storm runoff, rainfall, dry deposition (dust fall), and material from street surfaces. Samples were collected from drainage areas that represent four different types of land use: industrial, commercial, multiple-family residential, and single-family residential.

Data were collected during two wet weather seasons (1981-82 and 1982-83). The results of the USGS work are summarized in Chapter 4 of this report. A complete discussion of the USGS results is included in the USGS project report. A draft of the USGS report was issued in November 1983, and the report is in the process of being finalized.

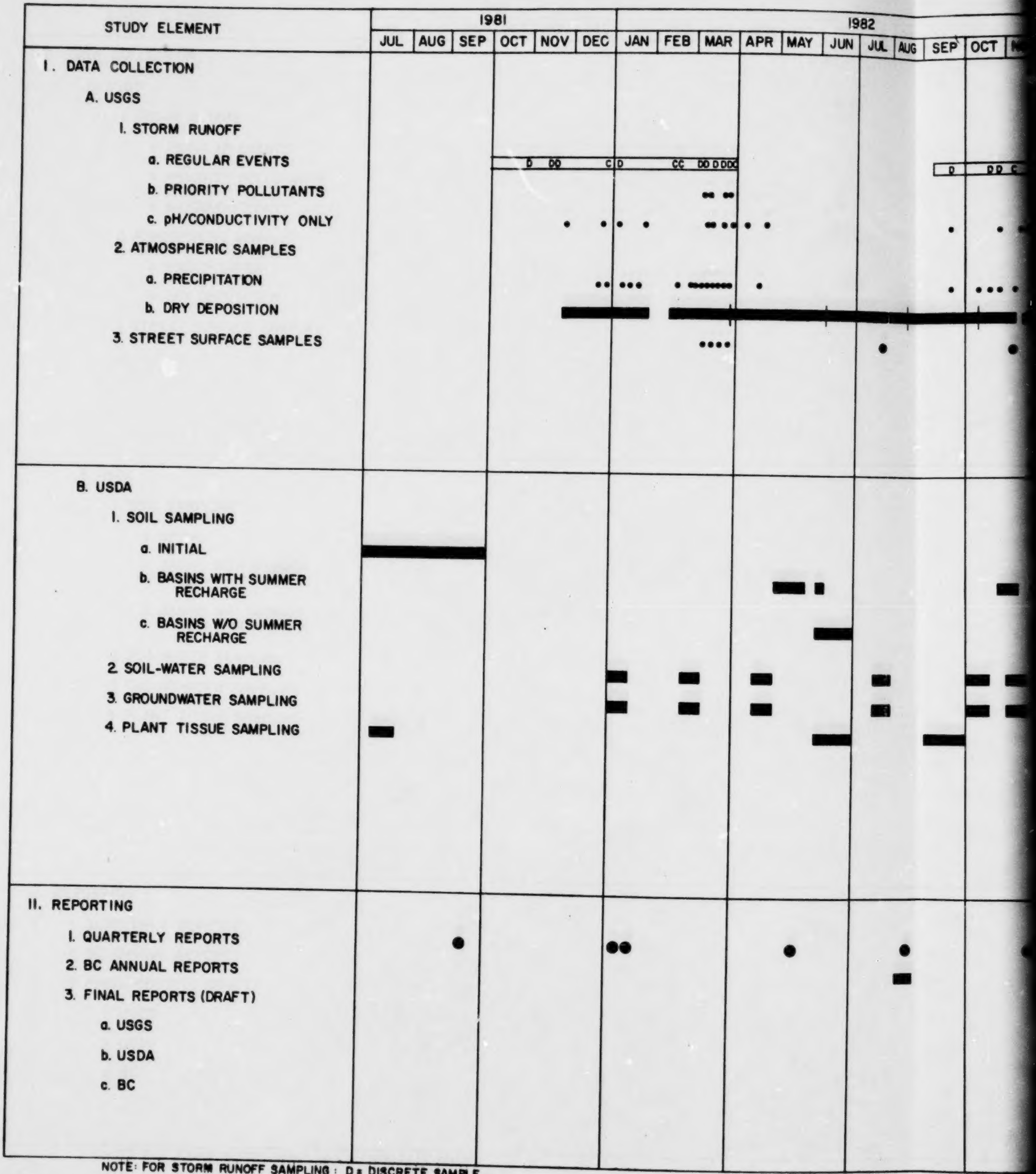
U.S. Department of Agriculture Work

The two main objectives of the USDA work were: (1) determine the physical, chemical, hydraulic, and biological properties of the soils that could influence the rate of percolation (recharge) and the deposition of runoff pollutants on or within the soils and (2) determine the quality of water in the soil and in the groundwater underlying each test basin. As shown on Figure 3-4, the USDA data collection work consisted of four main sampling components: soils, soil water, groundwater, and plant tissue. Five recharge basins were sampled.

Soils samples were collected in 1981, 1982, and 1983. Water sampling covered a 19-month period from January 1982 through July 1983. The results of the USDA work are summarized in Chapter 5 of this report. A complete discussion of the USDA results is included in the final USDA project report completed in September 1983.

Brown and Caldwell Work

Brown and Caldwell has been responsible for preparing interim reports and the overall final report for the project. Interim reports have been prepared quarterly and incorporate the quarterly technical reports submitted by USGS and USDA. The quarterly reports were also intended to summarize work progress to date, provide preliminary conclusions, and identify problems. Twelve quarterly reports were prepared; the first five were prepared by the District staff. Brown and Caldwell prepared the First and Second Annual Reports which were completed in October 1982 and September 1983, respectively. Brown and Caldwell also conducted the laboratory testing for metals and organics on soils and ground water samples.



NOTE: FOR STORM RUNOFF SAMPLING : D = DISCRETE SAMPLE
C = COMPOSITE SAMPLE

A 3-8

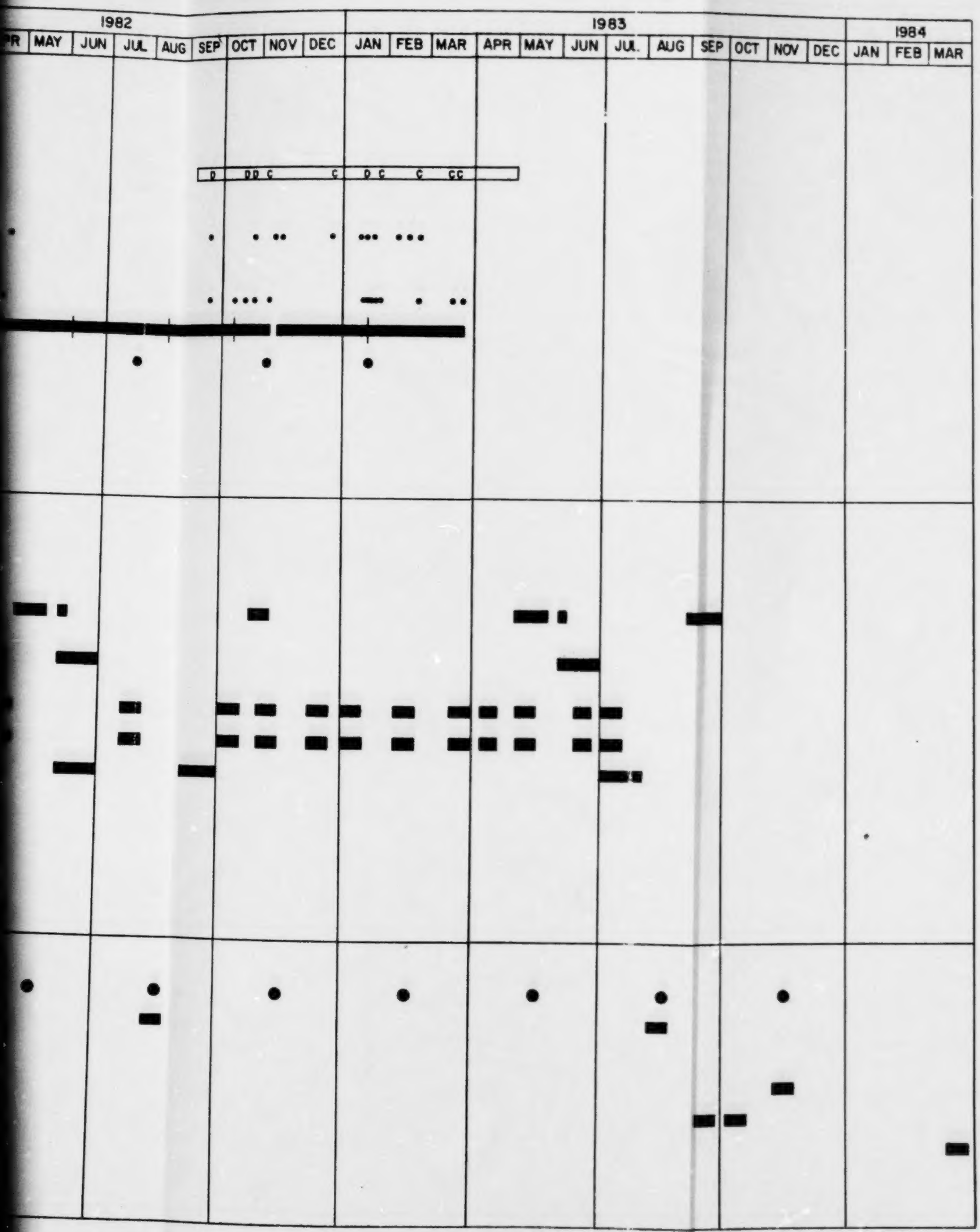


Figure 3-4 Data Collection and Report Status (As of March 1984)

B

CHAPTER 4

RUNOFF MONITORING PROGRAM

During the Fresno Nationwide Urban Runoff Program (NURP) project, a major effort was made to gather data on the quality and quantity of storm runoff, rainfall, and dry deposition. An extensive sampling program was conducted by the U.S. Geological Survey (USGS). The program, the data gathered by the USGS, and an analysis of the data are described in this chapter.

DESCRIPTION OF MONITORING PROGRAM

Extensive data were collected on the quantity and quality of storm runoff and rainfall and the quality of dry deposition and street particulate material. The USGS also collected a limited amount of data on the quality of dry weather runoff. Several runoff samples collected by USGS in 1982 were analyzed for the priority pollutants by the U.S. Environmental Protection Agency (EPA). The U.S. Department of Agriculture (USDA) collected data on the quality of summer recharge water, in addition to the soils, soil water, and groundwater data described in Chapter 5. Figure 4-1 shows the location of the USGS and USDA sampling sites. A wide range of water quality constituents were measured by USGS. Data were collected on the concentrations of conventional constituents such as nutrients, solids, and major ions; metals; and organic pesticides. A complete list of the constituents measured by USGS is presented in Appendix B. Samples were collected at one location from four land use types (single-family residential, multiple-family residential, commercial, and industrial) to characterize the pollutant concentrations and loads from these typical land uses in the Fresno area. The characteristics of the drainage areas sampled by USGS are presented in Table 4-1. The runoff coefficients for each drainage area are also shown in Table 4-1. The runoff coefficients were calculated for each storm by dividing the amount of runoff at the sampling points by the amount of precipitation that fell on the drainage area. The arithmetic average coefficients were determined by calculating the average of all storms. The average coefficients were also calculated by weighting each storm's runoff coefficient by the amount of runoff that occurred. Using this method, a storm with a large volume of runoff received more weight than a low-volume storm. These coefficients are used later in this chapter. It should be noted that the runoff coefficients for the industrial area are quite low since the street system and drainage system for this particular area are not complete.

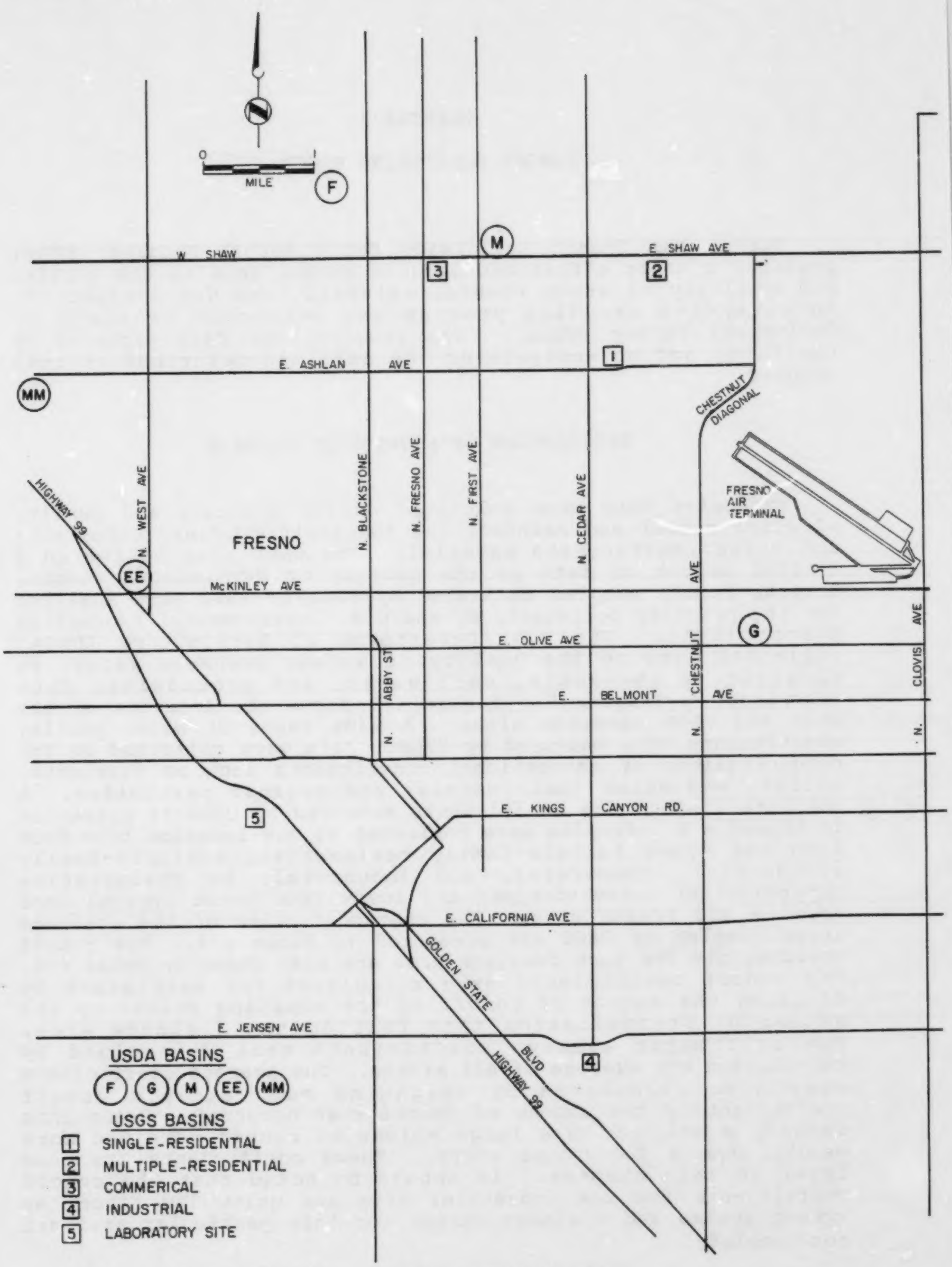


Figure 4-1 Location of Sampling Sites

Table 4-1. Key Characteristics of USGS Drainage Areas

Characteristic	Land use Single-family residential	Multiple-family residential	Commercial	Industrial
Drainage area, square miles	0.15	0.07	0.09	0.43
Land use, percent of drainage area				
Low-density residential	9.0	0	0	0
Medium-density residential	87.3	0	0	0
High-density residential	0	87.0	0	0
Commercial	0	0	100	0
Industrial	0	0	0	65.8
Idle or vacant	3.7	13.0	0	34.2
Population density, persons/square mile	7,700	16,400	0	0
Runoff coefficient				
Arithmetic average				
1981-82	0.19	0.29	0.93	0.18
1982-83	0.21	0.51	—	0.16
Both years	0.21	0.39	0.93	0.18
Flow-weighted average				
1981-82	0.22	0.38	1.05	0.24
1982-83	0.25	0.69	—	0.23

Detailed descriptions of the sampling programs are contained in reports prepared by USGS and USDA. The programs are summarized in this section.

Rainfall

The rainfall monitoring program was initiated in December 1981 and continued through March 1983. Eight samples were analyzed from each of the single-family residential and industrial sites in the 1981-82 rain season. During the 1982-83 rain season, eight samples were analyzed from three sites: the single-family residential and industrial sites and an additional site at the project laboratory. The laboratory site was established for additional data to determine if the single-family residential site rainfall quality was affected by its proximity to the flight path from the Fresno Airport, and if the industrial site quality was influenced by the adjacent environment. If these concerns were valid, data from the laboratory site might provide data more representative of the rainfall quality for the majority of the Fresno urban area. The samples were analyzed for nutrients, major ions, pesticides, and heavy metals. The rainfall and dry deposition samples were collected with a wet/dry sampler which allows collection of rain samples and dry fallout samples in separate buckets. A lid that is activated by a precipitation sensor moves to cover the "dry" collection bucket during storms. The "wet" bucket is covered between storms. Chemical analyses were conducted separately on the two kinds of samples.

Storm Runoff

The storm runoff sampling program was started in October 1981 and continued through March 1983. Samples were collected from the four land use types and analyzed for numerous physical, inorganic, organic, and biological constituents. During the first year of the sampling program, 16 storms were sampled. Flow-weighted composite samples were collected during 5 of the 16 storms. During the other 11 storms, discrete grab samples were collected and analyzed. The number of samples collected varied from storm to storm, but generally about 5 samples were collected. Flow, pH, and specific conductance were measured during an additional 18 storms. During the second year of the program, 11 storms were sampled. Composite samples were collected during 6 of the 11 storms and discrete samples were collected during the other 5 storms. Flow, pH, and specific conductance were measured during an additional 21 storms.

Dry Deposition

Dry deposition samples were collected at the single-family residential and industrial sites and routinely analyzed for nutrients, major ions, and lead. During the second year of the sampling program, the samples were also analyzed for other metals and one sample was analyzed for pesticides. A total of 19 samples were analyzed between November 1981 and March 1983.

Street Particulate Material

The street particulate data program was conducted between March 1982 and January 1983. Six samples were collected from the commercial site and five samples were collected from the other three sites. All of the streets in each of the four drainage areas were divided into 200-foot sections. Each section was assigned to a category as follows:

A--Residential Street
B--Intersection
C--Major Street

The entire street area in each drainage zone was broken into these three categories to determine the number of sections in each drainage zone. A total of 20 to 25 sections were sampled in each land use drainage area. The number of sections sampled in each of the three categories was based on the relative proportion of the number of sections in a particular category to the total number of sections in the drainage area. A commercial vacuum cleaner was used to collect a sample by vacuuming a 6-inch strip across the street from one curb to the other curb. The samples from the 20 to 25 sites in each drainage area were composited to produce one sample for analysis. The samples were analyzed for major ions, nutrients, metals, and organics.

Dry Weather Runoff

During August and September 1982, stage records of dry weather runoff were periodically collected at the two residential sites to estimate the "nuisance" runoff volume (i.e., runoff from lawn irrigation, car washing, and other activities during the summer months). Grab samples were collected from the residential sites on September 3, 1982, and analyzed for physical constituents, nutrients, major ions, metals, and pesticides.

Imported Recharge Water

Canal water from Fresno Irrigation District is used as recharge water in Basins MM and EE during the summer months. The USDA collected a limited amount of data on the quality of this recharge water during the summer of 1982. Samples were collected 24 times between June 22 and September 27, 1982, and analyzed for specific conductance, turbidity, and suspended solids. An additional sample was collected on July 15, 1982, and analyzed for specific conductance, pH, major ions, and nitrate. One sample was analyzed for metals and organics.

EPA Metals and Organics

EPA conducted two studies as part of the NURP project, using runoff samples collected by USGS during some of the storms.

1. Special Metals Project--EPA contract laboratories analyzed two grab samples from each of the four land use sites during a storm on January 4, 1982. The samples were analyzed for 29 metals. Total, total recoverable, and dissolved fractions were measured.

2. Priority Pollutant Sampling Program--EPA contract laboratories analyzed samples from each of the four land use sites collected by USGS during four storms during March 1982. The samples were analyzed for all of the 129 priority pollutants except asbestos.

RESULTS

A summary of the results of the runoff monitoring program is presented in this section. A detailed discussion of the data is contained in the USGS project report. Table 4-2 presents a summary of the metals and organics data. The table indicates if each constituent was detected in precipitation, dry deposition, street particulate material, and storm runoff. The conventional constituents (nutrients, major ions, physical parameters) are not shown in the table because they were detected in each component of the study. The conventional constituents are identified later in this chapter. The metals were generally detected in all four components of the study. Lindane, chlordane, DDE, diazinon, and malathion were detected in all four components. Most of the organics listed in Table 4-2 were detected in runoff. Many were detected in rainfall and street particulates. Most of the organics were not detected in dry deposition. The data collected for each of the study components are presented in this section. The USGS collected an extensive amount of data on a great number of constituents. All of the data are not presented in this section. Data are presented on the constituents that are most important in terms of the potential for contamination of the water supply and the potential for health hazards associated with recreational activities within the basins.

Storm Characteristics

There was a total of 123 storms in the Fresno area during the rain seasons (September to April) of 1981-82 and 1982-83. Seventy-eight storms produced 0.10 inch or more of rain. According to the 104-year rainfall record collected by the National Weather Service, the average annual rainfall at the Fresno Air Terminal is 10.24 inches with 9.84 inches falling between September and April. During the study period, the rainfall was 110 percent of normal (10.79 inches) for the 1981-82 rain season and 240 percent of normal (23.56 inches) in the 1982-83 rain season. Information on the storm sampling program is presented in Table 4-3.

Multiple-linear regression was used to develop relationships between rainfall and the amount of runoff. The total amount

Table 4-2. Metals and Organics Detected in Fresno NURP Project

Constituent	Component[a]			Runoff	Constituent	Component[a]			Runoff
	Rainfall	Dry deposition	Street particulates			Rainfall	Dry deposition	Street Particulates	
Priority pollutant metals					Priority pollutant organics[b]				
Antimony	-	-	-	X	Aldrin	O	O	O	X
Arsenic	O	X	X	X	Anthracene	-	-	-	X
Beryllium	X	-	-	-	Benzo(a) pyrene	-	-	-	X
Cadmium	-	-	X	X	Benzo(b) fluoranthene	-	-	-	X
Chromium	X	X	X	X	α-BHC	-	-	-	X
Copper	X	X	X	X	γ-BHC (lindane)	X	X	X	X
Cyanide	-	-	-	X	Butyl benzyl phthalate	-	-	-	X
Lead	X	X	X	X	Chlordane	X	X	X	X
Mercury	X	X	O	X	Chrysene	-	-	-	X
Nickel	X	X	X	X	DDD	O	O	X	O
Zinc	X	X	X	X	DDE	X	X	X	X
Other metals					DDT	O	O	X	X
Aluminum	X	X	X	X	Dieldrin	X	O	X	X
Barium	X	-	-	X	Di-n-octyl phthalate	-	-	-	X
Boron	-	-	-	X	Endosulfan	X	O	X	X
Cobalt	-	-	-	X	Endrin	O	O	O	X
Iron	X	X	X	X	Fluoranthene	-	-	-	X
Lithium	X	-	-	X	Heptachlor	O	O	X	X
Manganese	X	X	X	X	Heptachlor epoxide	O	O	X	X
Molybdenum	-	-	-	X	4-nitrophenol	-	-	-	X
Strontium	X	-	-	X	Total PCB	X	O	X	X
Titanium	-	-	-	X	Pentachlorophenol	-	-	-	X
Vanadium	-	-	-	X	Phenol	X	-	-	X
					Pyrene	-	-	-	X
					Other organics[c]				
					Diazinon	X	X	X	X
					Dibromochloropropane	-	-	-	X
					Ethion	X	O	O	O
					Malathion	X	X	X	X
					Methoxychlor	X	X	O	X
					Methyl parathion	X	O	O	X
					Parathion	X	O	X	X
					Silvex	O	O	-	X
					Trithion	O	O	X	X
					2,4-D	X	O	O	X

[a] Table symbols : X indicates detected; O indicates not detected; - indicates not measured.

[b] The runoff samples were analyzed for the complete list of priority pollutants. Those pollutants not listed in the table were not detected in any of the samples.

[c] The samples were analyzed for the following additional organics but concentrations were always less than the analytical detection limit: perthane, methomyl, propham, polychlorinated napthalenes, 2,4,5-T, sevin, mirex, methyl trithion, and 2,4-DP.

Table 4-3. Storm Summary

Storm characteristic	Rain season[a]		
	1981-82	1982-83	Total
Amount of rain, inches			
Produced by storms ≥0.1 inch	10.3	19.95	30.25
Produced by storms <0.1 inch	0.49	3.61	4.10
Total	10.79	23.56	34.35
Number of storms			
Storms ≥0.1 inch	34	44	78
Storms <0.1 inch	22	23	45
Total	56	67	123
Number of storms sampled			
Storms ≥0.1 inch			
All constituents			
Runoff	15	8	23
Rain	13	16	29
Specific conductance and pH			
Runoff	12	18	30
Rain	5	8	13
Storms <0.1 inch			
All constituents			
Runoff	1	3	4
Rain	0	1	1
Specific conductance and pH			
Runoff	6	3	9
Rain	0	0	0
Total storms sampled			
Runoff	34	32	66
Rain	18	25	43

[a] Does not include storms which occurred between May and August of these two years.

of rainfall in each storm, the number of dry hours since the last storm, and the maximum 20-minute rainfall intensity were regressed against the amount of runoff in each land use drainage area. The total amount of rainfall for each storm was the only significant variable at the 0.05 level for the commercial site. All three variables were significant for the multiple-family residential site. The total amount of rainfall and the number of dry hours since the last storm were significant for the single-family residential and industrial sites. The total amount of rainfall was probably the only significant variable at the commercial site because the drainage area is 98.9 percent impervious. There are no large areas of exposed soil where runoff can vary with the degree of soil saturation and infiltration rate. If the number of hours since the last storm is a significant variable, it indicates that there are exposed soil areas in the drainage area that must reach saturation before runoff occurs. If the maximum 20-minute rainfall intensity is a significant variable, it indicates that the drainage area soils have a high infiltration rate, and the rainfall rate must exceed the infiltration rate before runoff occurs from these pervious soil areas.

The rainfall-runoff coefficients were determined for each storm by dividing the runoff volume by the rainfall volume falling on the drainage area. The average rainfall-runoff coefficients for each drainage area during the study period are listed in Table 4-1.

Rainfall

Rainfall quality samples were collected during 18 storms in the 1981-82 season and 25 storms in the 1982-83 season. During 30 of these storms, the samples were analyzed for all of the constituents. During the remaining 13 storms, only specific conductance and pH were measured.

Conventional Constituents. Table 4-4 presents the ranges and mean concentrations of conventional constituents at the three sampling sites (single-family residential, industrial, and laboratory). Conventional refers to those constituents which are not metals or organics and consist of physical properties, cations, and anions. The data show that the rainfall quality was generally similar at the three stations. The concentrations of most constituents were lowest at the single-family residential and laboratory sites and highest at the industrial site. Statistical testing conducted by USGS showed that there were statistically significant differences at the 0.05 level in the concentrations of dissolved ammonia and pH between the single-family residential and industrial sites. The differences could be due to the discharge of industrial plant emissions into the atmosphere near the sampling site. The statistical testing showed that there were no differences at the 0.05 significance level in constituent concentrations at the single-family residential site between the two rain seasons. At the industrial site, only dissolved phosphorus and dissolved organic carbon were significantly different in the two rain seasons.

Table 4-4. Ranges and Mean Concentrations of Conventional Constituents in Rainfall

		Concentration								
		Single-family residential			Industrial			Laboratory		
Constituent	Units	N[a]	Range	Mean	N[a]	Range	Mean	N[a]	Range	Mean
Specific conductance	umhos/cm	32	2.4-57	13.8	36	3.0-52	13.9	16	4.0-30	11.8
pH	standard units	33	4.7-7.7	5.9	37	5.0-7.7	6.4	16	4.7-7.4	6.0
Alkalinity	mg/l as $CaCO_3$	16	3.0-9.0	7.2	15	4.0-10.0	7.5	3	5.0-7.0	6.3
COD	mg/l	15	7.0-30	14.5	14	<10-27	16	5	<10-23	16.4
Dissolved nitrogen	mg/l as N	10	0.4-10	2.0	10	5.0-7.7	6.4	6	0.7-2.6	1.3
Dissolved organic nitrogen	mg/l as N	10	0.1-0.99	0.43	9	0.08-2.7	0.70	4	0.1-0.74	0.49
Dissolved ammonia	mg/l as N	13	0.1-0.74	0.37	12	0.19-1.3	0.70	7	0.2-0.76	0.46
Dissolved nitrite	mg/l as N	13	<0.02-0.04	0.02	12	<0.02-0.04	0.02	7	<0.02-0.05	0.02
Dissolved nitrate + nitrite	mg/l as N	16	<0.01-0.60	0.22	15	<0.09-0.96	0.25	8	<0.1-0.56	0.23
Dissolved phosphorus	mg/l as P	16	<0.01-0.14	0.03	15	0.01-0.26	0.08	7	<0.01-0.04	0.02
Dissolved orthophorphorus	mg/l as P	13	<0.01-0.04	0.01	12	<0.01-0.06	0.02	8	<0.01-0.07	0.02
Dissolved organic carbon	mg/l	13	2.1-6.2	3.6	14	0.3-6.2	3.8	7	1.8-16	6.9
Dissolved calcium	mg/l	16	0.1-1.3	0.48	15	0.1-1.5	0.60	3	0.2-0.92	0.47
Dissolved magnesium	mg/l	16	<0.01-0.18	0.08	15	<0.01-0.24	0.09	3	<0.01-0.08	0.06
Dissolved sodium	mg/l	16	<0.2-1.1	0.47	15	0.2-1.2	0.50	3	0.2-0.7	0.43
Dissolved potassium	mg/l	16	<0.10-0.30	0.14	15	0.10-0.60	0.24	3	0.20-0.30	0.23
Dissolved chloride	mg/l	16	0.10-1.2	0.46	15	0.20-1.0	0.53	3	0.30-1.2	0.60
Dissolved sulfate	mg/l	14	<0.50-5.0	3.4	12	0.60-5.0	3.3	3	1.1-1.4	1.2
Dissolved silica	mg/l	8	<0.01-0.60	0.25	7	0.01-0.60	0.29	0		

[a] N = number of samples.

Metals. The ranges and median concentrations of metals at the three sites are presented in Table 4-5. For some metals, the median concentrations were similar at the three sites. Only aluminum, copper, zinc, lead, and iron concentrations varied appreciably among the three sites. The lowest concentrations were generally found at the laboratory site and the highest concentrations were found at the industrial site. Statistical testing conducted by USGS showed that there were no statistically significant differences in the concentrations between the three sites.

Table 4-5. Ranges and Median Concentrations of Metals in Rainfall

	Total recoverable metal concentrations, ug/l								
	Single-family residential			Industrial			Laboratory		
Constituent	N[a]	Range	Median	N[a]	Range	Median	N[a]	Range	Median
Priority pollutant metals									
Arsenic[b]	7	<1.0	<1.0	7	<1.0	<1.0	5	<1.0-1.0	<1.0
Chromium	3	<1.0	<1.0	4	<1.0-1.0	<1.0	3	<1.0	<1.0
Copper	3	<1.0-6	4.0	4	1.0-12	6.0	3	<2.0-8.0	2.0
Cyanide[b]	1		0.01	1		0.01	1		<0.01
Lead	16	<1.0-61	8.0	15	<1.0-51	7.0	6	2.0-44	5.0
Mercury	7	<0.1-0.1	0.1	7	<0.1-0.2	<0.1	5	<0.1-0.1	<0.1
Nickel	9	<1.0-12	5.0	9	<1.0-11	5.0	6	2.0-9.0	5.0
Zinc	3	30-60	60	4	30-90	55	3	20-30	20
Other metals									
Aluminum	3	30-80	50	4	60-580	100	3	60-90	80
Iron	9	10-1,400	90	9	10-2,800	130	6	40-1,300	80
Manganese	9	<10-60	10	9	<10-80	10	6	<10-40	10

[a] N = number of samples.
[b] Total arsenic and total cyanide.

Organics. The rainfall samples were analyzed for 32 organic constituents including many of the pesticides commonly used in the agricultural areas surrounding Fresno. Only 14 of these constituents were found at concentrations exceeding the analytical detection limit in at least one sample. The ranges and median concentrations of these 14 organic constituents are presented in Table 4-6. The organics detected in rainfall were generally found at all three sites. Statistical testing conducted by USGS showed that there were no statistically significant differences in the constituent concentrations at the three sampling sites except for total phenol. The median concentrations of most constituents were less than the detection limit (0.01 to 0.1 ug/l) at each of the three sites. The organophosphorus compounds, parathion, malathion, and diazinon, were the most prevalent pesticides detected in rainfall. Chlordane, lindane, methoxychlor, endosulfan, and 2,4-D were also found in rainfall. Their presence in rainfall is probably due to their use in the agricultural area around Fresno. Parathion and diazinon are insecticides used in the San Joaquin Valley primarily as dormant sprays on fruit trees. They are commonly applied with a truck-mounted sprayer that tends to suspend large quantities of spray in the air. Lindane is commonly applied by aerial spraying from an airplane. The USGS project report further discusses the occurrence of pesticides in rainfall and runoff.

Table 4-6. Ranges and Median Concentrations of Organics in Rainfall

Constituent[b]	Concentration,[a] ug/l					
	Single-family residential		Industrial		Laboratory	
	Range	Median	Range	Median	Range	Median
Priority pollutant organics						
Chlordane	<0.10-0.40	<0.10	<0.10-0.40	<0.10	<0.10	<0.10
DDE	<0.01-0.01	<0.01	<0.01-0.02	<0.01	<0.01-0.02	<0.01
Dieldrin	<0.01-0.01	<0.01	<0.01-0.01	<0.01	<0.01-0.01	<0.01
Endosulfan	<0.01-0.04	<0.01	<0.01-0.08	<0.01	<0.01-0.07	<0.01
Lindane	<0.01-0.02	0.01	<0.01-0.04	0.01	<0.01-0.01	0.01
Total PCB	<0.10	<0.10	<0.10-0.10	<0.10	<0.10	<0.10
Phenol	1.0-25	8.0	2.0-15	4.0	2.0-14	6.0
Other organics						
Diazinon	0.01-0.42	0.08	0.01-0.93	0.14	0.01-0.26	0.11
Ethion	<0.01	<0.01	<0.01	<0.01	<0.01-0.01	<0.01
Malathion	<0.01-0.11	0.03	<0.01-0.11	0.02	0.01-0.10	0.03
Methoxychlor	<0.01-0.05	<0.01	<0.01-0.12	<0.01	<0.01-0.04	<0.01
Methyl parathion	<0.01-0.07	<0.01	<0.01	<0.01	<0.01	<0.01
Parathion	<0.01-0.86	0.20	<0.01-1.0	0.16	<0.01-0.66	0.16
2,4-D	<0.01-0.04	<0.01	<0.01-0.08	<0.01	<0.01-0.04	<0.01

[a] The median concentrations are based on 20 samples collected at the single-family residential and industrial sites and 10 samples collected at the laboratory site.

[b] The samples were analyzed for the following organics but concentrations were always less than the analytical detection limit: methomyl, propham, polychlorinated napthalenes, aldrin, DDT, DDD, endrin, toxaphene, heptachlor, heptachlor epoxide, 2,4,5-T, sevin, mirex, perthane, silvex, trithion, methyl trithion, and 2,4-D.

Storm Runoff

Storm runoff quality and quantity were measured at the single-family residential, multiple-family residential, commercial, and industrial sites. Storm runoff quality samples were collected during 34 storms in the 1981-82 rain season and 32 storms in the 1982-83 rain season. During 27 of these storms, the samples were analyzed for all of the constituents listed in Appendix B. During the remaining 39 storms, only specific conductance and pH were measured. The tabulations in this section include all the discrete sample data, but do not include the results from the several composite samples.

Conventional Constituents. Table 4-7 presents the ranges and mean concentrations of conventional constituents at the four sampling sites. Statistical testing showed that the concentrations of most of the conventional constituents were significantly higher at the industrial site than at the other three sites. The concentrations at the other three sites were generally similar. The lowest concentrations were generally found at the single-family residential site. The runoff concentrations of conventional constituents were higher than the concentrations in rainfall. Most concentrations were an order of magnitude higher in runoff than in rainfall.

Table 4-7. Ranges and Mean Concentrations of Conventional Constituents in Runoff

Constituent	Units	Concentration											
		Single-family residential			Multiple-family residential			Commercial			Industrial		
		N[a]	Range	Mean	N[a]	Range	Mean	N[a]	Range	Mean	N[a]	Range	Mean
Turbidity	NTU	49	1.7-900	57	72	2.0-320	49	71	1.6-300	31	83	1.0-800	160
Specific conductance	umhos/cm	121	15-222	56	230	17-606	66	256	8.0-808	90	285	96-9,960	404
pH	Standard units	97	6.5-8.3	7.2	169	6.4-8.8	7.1	203	6.1-8.9	6.9	221	4.9-7.5	6.7
Hardness	mg/l as $CaCO_3$	62	4.0-70	20	85	6.0-230	30	95	3.0-330	49	101	17-410	65
Alkalinity	mg/l as $CaCO_3$	65	7.0-73	19	89	5.0-150	25	96	1.0-257	36	101	5.0-221	84
Oil and grease	mg/l	11	1.0-8.0	3.0	17	0-5.0	1.5	18	0-26	4.2	15	0-80	11
Suspended solids	mg/l	64	9.0-1,540	246	86	8.0-4,300	634	94	2.0-3,720	264	100	51-2,770	684
Dissolved solids	mg/l	64	9.0-224	63	81	14-775	104	87	1.0-1,010	143	93	77-5,870	423
BOD-ultimate	mg/l	22	2.3-81	21	45	5.2-150	23	44	3.4-64	13	42	39-830	189
BOD-5-day	mg/l	22	2.1-53	15	45	3.1-110	15	44	2.7-30	8.4	42	30-330	149
COD	mg/l	34	27-290	106	58	31-1,400	157	50	12-460	95	56	150-2,580	620
Dissolved nitrogen	mg/l as N	64	0.63-21	4.8	86	0.8-33	5.5	83	0.7-66	8.1	79	4.0-54	20
Dissolved organic nitrogen	mg/l as N	62	0.19-12	2.6	84	0.10-25	3.0	85	0.01-27	3.6	86	0.01-38	12
Dissolved ammonia	mg/l as N	65	0.12-6.4	1.4	83	<0.01-7.3	1.4	87	0.22-17	2.2	86	0.90-20	6.6
Dissolved nitrite	mg/l as N	31	0.02-0.13	0.05	53	0.01-0.41	0.05	45	0.02-0.56	0.05	53	0.01-0.55	0.21
Dissolved nitrate	mg/l as N	25	0.18-2.1	0.75	45	0.10-6.6	0.89	39	0.14-4.5	0.78	42	0.01-3.3	1.2
Total phosphorus	mg/l as P	65	0.10-2.4	0.63	89	0.01-5.0	0.81	87	0.03-9.1	0.63	90	0.90-20	6.6
Dissolved phosphorus	mg/l as P	65	0.09-1.6	0.37	87	0.01-4.7	0.58	87	0.02-8.0	0.45	89	0.40-11	4.9
Dissolved orthophorphorus	mg/l as P	64	0.09-1.6	0.31	88	0.01-2.1	0.38	87	<0.02-4.8	0.28	66	0.60-9.0	3.7
Dissolved organic carbon	mg/l	36	4.4-550	75	58	4.6-460	64	47	4.4-260	54	56	20-2,300	190
Suspended organic carbon	mg/l	33	0.8-17	3.2	54	1.3-15	3.7	46	0.90-10	2.5	54	5.8-41	25
Dissolved calcium	mg/l	65	1.3-18	5.8	87	2.0-65	8.3	96	0.80-100	13.6	101	4.0-120	15
Dissolved magnesium	mg/l	65	0.01-6.2	1.3	87	0.20-16	2.1	96	0.10-22	3.5	101	1.6-26	6.4
Dissolved sodium	mg/l	65	0.70-18	3.9	87	1.0-49	6.8	96	0.60-37	6.8	102	5.7-1,800	74
Dissolved potassium	mg/l	65	0.80-9.8	3.3	87	0.8-19	3.4	96	0.30-15	2.9	99	5.2-62	24
Dissolved chloride	mg/l	64	0.60-14	3.4	88	0.60-65	5.1	95	0.20-31	5.5	102	4.8-3,000	112
Dissolved sulfate	mg/l as SO_4	61	4.2-27	8.3	88	3.6-76	12.2	95	3.1-190	21	102	<5.0-110	25
Dissolved silica	mg/l as SiO_2	44	0.34-27	3.0	68	1.5-25	4.7	64	0.50-44	3.2	74	1.6-30	5.4

[a] N = number of samples.

Metals. The ranges and median concentrations of metals in runoff at the four sites are presented in Table 4-8. Cyanide was the only constituent which was consistently below the analytical detection limit. All of the other metals were present at concentrations that exceeded the detection limit in at least one sample. For most metals, the median concentrations were similar at the two residential and commercial sites and considerably higher at the industrial site. The concentrations of iron, aluminum, and manganese at the multiple-family residential site were statistically significantly higher than at the single-family residential site. The higher concentrations may be due to soil erosion from undeveloped land in the multiple-family residential drainage area and not to differences in urban runoff. The arsenic and zinc concentrations were higher at the industrial site than the other sites. The lead concentrations were highest at the residential sites. The runoff concentrations of metals were generally 2 to 70 times higher than the concentrations in rainfall.

Table 4-9 presents the median concentrations of total recoverable and dissolved metals at each of the four sampling sites. The particulate fraction of most metals was much larger than the dissolved fraction. Less than 25 percent of the aluminum, chromium, iron, and lead was in the dissolved form at all four sites. Arsenic was the only metal which was predominantly in the dissolved form at all sites.

Organics. The runoff samples were analyzed for 34 organic constituents. Only 19 of these constituents were found at concentrations exceeding the analytical detection limit in at least one sample. The ranges and median concentrations of these 19 organic constituents are presented in Table 4-10. The organics detected in runoff were generally found at all four sites. The median concentrations of most constituents were less than the detection limit (0.01 to 0.1 ug/l) at each of the four sites. The median concentrations of lindane, phenol, diazinon, malathion, parathion, and 2,4-D exceeded the detection limits at all four sites. All of these constituents were also found in the precipitation samples. Chlordane and DDE were also found at some of the sampling sites. Chlordane occurred more frequently in runoff than in rainfall. The highest concentrations of chlordane and DDE were found at the single-family residential site and the industrial site, while the lowest concentrations were found at the commercial site. This is probably due to the use of pesticides in landscaping and gardens in residential areas and the manufacturing, storage, transport, or handling of pesticides in industrial areas. There is minimal landscaping in the commercial area, so it is not surprising to find low levels of pesticides in commercial runoff.

Table 4-8. Ranges and Median Concentrations of Metals in Runoff

Metals	Total recoverable metal concentration, ug/l											
	Single-family residential			Multiple-family residential			Commercial			Industrial		
	N[a]	Range	Median	N[a]	Range	Median	N[a]	Range	Median	N[a]	Range	Median
Priority pollutant metals												
Arsenic[b]	64	<1.0-8.0	1.0	87	<1.0-16	2.0	95	<1.0-17	2.0	16	1.0-67	14
Cadmium	31	<1.0-4.0	1.0	53	<1.0-6.0	1.0	49	<1.0-12	1.0	70	<1.0-4.0	1.0
Chromium	48	<1.0-40	8.5	70	1.0-62	15	68	1.0-37	11	86	<1.0-51	14
Copper	47	4.0-180	14	70	7.0-270	22	68	6.0-380	18	86	30-400	66
Cyanide[b]	5	<0.01	<0.01	5	<0.01	<0.01	6	<0.01	<0.01	3	<0.01	<0.01
Lead	63	15-2,100	170	91	25-940	170	95	9.0-1,200	100	107	16-360	74
Mercury	64	<0.10-8.6	0.10	88	<0.10-1.6	0.20	95	<0.10-0.50	0.10	107	<0.10-2.5	0.10
Nickel	62	1.0-85	11	91	2.0-310	19	94	1.0-120	10	107	4.0-98	24
Zinc	47	30-1,300	90	70	60-1,800	170	68	50-3,400	150	86	280-3,100	535
Other metals												
Aluminum	17	530-20,000	3,400	17	1,600-37,000	6,300	19	120-45,000	3,400	16	3,000-18,000	7,000
Iron	64	160-29,000	1,700	91	450-72,000	5,600	95	140-57,000	1,600	107	480-62,000	9,000
Manganese	32	20-480	110	38	40-1,600	200	46	30-1,700	280	37	170-1,600	360

[a] N = number of samples.

[b] Total arsenic and total cyanide.

Table 4-9. Total Recoverable and Dissolved Metals Concentrations in Runoff

Metals	Median concentration, ug/l							
	Single-family residential		Multiple-family residential		Commercial		Industrial	
	Total recoverable	Dissolved	Total recoverable	Dissolved	Total recoverable	Dissolved	Total recoverable	Dissolved
Aluminum	3,400	50	6,300	195	3,400	75	7,000	150
Arsenic[a]	1.0[a]	1.0	2.0[a]	1.0	2.0[a]	1.0	14[a]	9.0
Cadmium	1.0	2.0	1.0	<1.0	1.0	<1.0	1.0	<1.0
Chromium	8.5	<1.0	15	<1.0	11	<1.0	14	<1.0
Copper	14	5.0	22	5.0	18	4.0	66	15
Cyanide[a]	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Iron	1,700	91	5,600	150	1,600	89	9,000	370
Lead	170	25	170	12	100	12	74	9.0
Manganese	110	23	200	56	280	105	360	130
Mercury	0.1	<0.1	0.2	<0.1	0.1	<0.1	0.1	0.1
Nickel	11	4.0	19	5.0	10	4.0	24	8.0
Zinc	90	43	170	50	150	80	535	190

[a] Total arsenic and total cyanide.

Table 4-10. Ranges and Median Concentrations of Organics in Runoff

Constituent[a]	Concentration, ug/l											
	Single-family residential			Multiple-family residential			Commercial			Industrial		
	N[b]	Range	Median	N[b]	Range	Median	N[b]	Range	Median	N[b]	Range	Median
Priority pollutant organics												
Aldrin	16	<0.1	<0.01	27	<0.01–0.02	<0.01	24	<0.01	<0.01	19	<0.01	<0.01
Chlordane	16	0.10–0.30	0.10	26	<0.10–1.2	0.10	23	<0.10–0.30	0.10	19	<0.10–0.30	<0.10
DDE	16	<0.01–0.01	<0.01	27	<0.01–0.06	<0.01	24	<0.01–0.01	0.01	19	<0.01–0.03	0.01
DDT	16	<0.01–0.01	<0.01	27	<0.01–0.01	<0.01	24	<0.01	<0.01	19	<0.01	<0.01
Dieldrin	16	<0.01–0.01	<0.01	27	<0.01–0.02	<0.01	24	<0.01–0.01	<0.01	19	<0.01–0.02	<0.01
Endosulfan	16	<0.01–0.01	<0.01	27	<0.01	<0.01	24	<0.01	<0.01	19	<0.01–0.02	<0.01
Endrin	16	<0.01–0.01	<0.01	27	<0.01	<0.01	24	<0.01	<0.01	19	<0.01	<0.01
Lindane	16	0.01–0.06	0.03	27	<0.01–0.03	0.01	24	0.01–0.03	0.01	19	0.01–0.27	0.03
PCB	16	<0.10	<0.10	27	<0.10	<0.01	24	<0.10	<0.01	19	<0.10	<0.10
Phenol	5	13–35	18	9	6.0–41	16	9	6.0–52	17	5	8.0–500	20
Other organics												
Diazinon	16	0.11–1.1	0.27	27	0.06–8.1	0.22	24	0.13–18	0.39	18	0.14–3.3	0.53
Dibromochloropropane	4	<0.003–0.003	<0.003	7	<0.003–0.004	<0.003	8	<0.003–0.01	<0.003	7	<0.003–0.005	<0.003
Malathion	16	0.19–13	0.99	27	0.08–14	0.49	24	0.08–1.4	0.23	18	0.20–3.0	0.44
Methoxychlor	16	<0.01–0.19	<0.01	27	<0.01–0.02	<0.01	24	<0.01	<0.01	19	<0.01–0.03	<0.01
Methyl parathion	16	<0.01–0.03	<0.01	27	<0.01	<0.01	24	<0.01–0.03	<0.01	18	<0.01	<0.01
Parathion	16	<0.01–0.92	0.13	27	<0.01–2.5	0.06	24	<0.01–0.90	0.09	18	<0.01–0.38	<0.01
Silvex	16	<0.01–0.03	<0.01	26	<0.01	<0.01	23	<0.01	<0.01	19	<0.01–0.07	<0.01
2,4-D	16	<0.01–1.7	0.07	26	<0.01–3.7	0.08	23	<0.01–0.63	0.01	19	<0.01–3.2	0.03
Trithion	16	<0.01	<0.01	27	<0.01	<0.01	24	<0.01	<0.01	19	<0.01–0.10	<0.01

[a] The samples were analyzed for the following organics but concentrations were always less than the analytical detection limit: polychlorinated napthalenes, DDD, heptachlor, heptachlor epoxide, mirex, perthane, toxaphene, ethion, methyl trithion, methomyl, propham, sevin, 2,4-DP, 2,4,5-T.

[b] N = number of samples.

Dry Deposition

Dry deposition samples were collected at the single-family residential and industrial sites between storms for ten periods during the study period. The samples were analyzed for all of the constituents listed in Table B-1 in Appendix B. It is difficult to collect dry deposition data that are representative of a large area. The amount of material collected in a dry deposition collector bucket is influenced by the location of the bucket with respect to the ground, wind conditions, and the activity in the surrounding area. The two deposition collectors for this study were mounted in similar positions approximately 3 meters above the ground on the roof of the study's instrumentation shelters. They were located about 10 to 20 meters from light traffic-density streets.

Conventional Constituents. Table 4-11 presents the ranges and mean concentrations of conventional constituents at the single-family residential and industrial sites. The dry deposition quality was generally similar at the two sites. The nitrogen concentrations were higher at the residential site and the phosphorus concentrations were higher at the industrial site.

Table 4-11. Ranges and Mean Concentrations of Conventional Constituents in Dry Deposition

Constituent	Concentration, mg/kg					
	Single-family residential			Industrial		
	N[a]	Range	Mean	N[a]	Range	Mean
Total solids	9	20-527	135	10	41-856	211
Total organic nitrogen	7	10,300-70,000	24,357	9	12,400-129,000	52,133
Total ammonia	9	<114-82,800	13,729	10	1,050-46,800	11,989
Dissolved nitrite + nitrate	9	1,890-295,000	41,263	10	1,200-42,200	9,328
Total phosphorus	9	588-6,900	2,479	10	1,290-10,600	5,156
Total orthophosphorus	9	304-5,860	1,504	10	553-25,800	4,489
Dissolved organic carbon	7	30,400-266,000	118,357	10	10,100-390,000	117,700
Dissolved calcium	9	3,770-121,000	24,440	10	2,760-31,100	12,419
Dissolved magnesium	9	638-13,800	5,005	10	780-21,000	5,949
Dissolved sodium	9	<4,260-55,200	16,011	10	1,380-21,000	9,068
Dissolved potassium	9	1,890-24,100	8,034	10	2,760-74,200	18,466
Dissolved chloride	9	498-58,600	14,965	10	2,300-25,800	9,364
Dissolved sulfate	9	4,260-250,000	79,232	10	<922-178,000	63,777
Dissolved silica	4	3,430-24,100	12,605	5	1,050-7,320	3,000

[a] N = number of samples.

Metals. The ranges and median concentrations of metals at the two sites are presented in Table 4-12. Based on the limited data collected, the median concentrations of most metals were similar at the two sites. The lead and mercury concentrations were higher at the single-family residential site, and the chromium concentration was higher at the industrial site. The USGS estimated the deposition rates and found that the rates for most constituents were fairly constant throughout the year.

Table 4-12. Ranges and Median Concentrations of Metals in Dry Deposition

Constituent	Total recoverable metal concentration, mg/kg					
	Single-family residential			Industrial		
	N[a]	Range	Median	N[a]	Range	Median
Priority pollutant metals						
Arsenic[b]	5	4.5-50	19	5	4.6-24	14
Chromium	5	57-250	85	5	28-289	143
Copper	5	91-1,950	481	5	115-689	443
Lead	9	304-8,280	1,640	10	140-1,610	592
Mercury	5	0.91-10	3.9	5	0.74-4.4	1.8
Nickel	5	21-350	94	5	28-329	100
Zinc	5	543-4,000	2,340	5	369-2,440	1,760
Other metals						
Aluminum	5	9,950-40,500	12,300	5	8,290-33,300	10,400
Iron	5	15,200-50,000	17,500	5	11,100-42,400	15,600
Manganese	5	362-1,500	385	5	276-1,330	444

[a] N = number of samples.

[b] Total arsenic.

Organics. One dry deposition sample from each site was analyzed for 31 organic constituents but only 6 were found at concentrations exceeding the analytical detection limit. These data are presented in Table 4-13. The organics concentrations of chlordane, DDE, lindane, diazinon, malathion, and methoxychlor were higher at the single-family residential site than at the industrial site. All of the pesticides detected in dry deposition were also detected in precipitation and runoff.

Table 4-13. Concentrations of Organics in Dry Deposition

Constituent[b]	Concentration,[a] ug/kg	
	Single-family residential	Industrial
Priority pollutant organics		
Chlordane	610	270
DDE	30	13
Lindane	30	13
Other organics		
Diazinon	180	120
Malathion	850	200
Methoxychlor	30	<0.01

[a] Based on one sample.

[b] The samples were analyzed for the following organics, but concentrations were less than the analytical detection limit: aldrin, DDD, DDT, dieldrin, endosulfan, endrin, ethion, PCB, polychlorinated napthalenes, heptachlor, heptachlor epoxide, methyl parathion, methyl trithion, mirex, parathion, perthane, silvex, toxaphene, trithion, 2,4-D, 2,4-DP, 2,4,5-T, methomyl, propham, and sevin.

Street Particulate Material

Street particulate samples were collected from each of the four land use types from March 1982 through January 1983. Six samples were collected in the commercial drainage area and five samples were collected in each of the other drainage areas. The initial objectives of the sampling program were to determine a particulate buildup curve for each land use, to determine which constituents were present, and to determine the concentrations of those constituents on the street surfaces. Due to problems with data collection, it was not possible to determine buildup curves.

Conventional Constituents. Table 4-14 presents the ranges and mean concentrations of conventional constituents at the four sampling sites. The concentrations of most constituents were highest at the commercial site and lowest at the multiple-family residential site. The high concentrations at the commercial site may be due to construction activities in the drainage basin. The street particulate concentrations of conventional constituents were consistently one to two orders of magnitude lower than the concentrations in dry deposition; however, the quantity of street particulate material greatly exceeded the amount of dry deposition material.

Table 4-14, Ranges and Mean Concentrations of Conventional Constituents in Street Particulates

Constituent	Concentration, mg/kg											
	Single-family residential			Multiple-family residential			Commercial			Industrial		
	N[a]	Range	Mean	N[a]	Range	Mean	N[a]	Range	Mean	N[a]	Range	Mean
COD	5	44,000-66,000	52,400	5	25,000-49,000	36,200	6	91,000-150,000	123,500	5	30,000-65,000	40,800
Volatile solids	5	38,100-98,000	62,540	5	19,600-53,200	27,720	6	41,200-98,300	73,168	5	19,900-31,100	26,300
Total nitrogen	4	507-1,210	878	4	255-580	429	6	643-1,910	1,202	3	347-574	453
Total ammonia	5	19-64	35	5	22-38	30	6	24-100	49	5	5.8-80	38
Total nitrite	3	<2.0->2.0	2.0	3	<2.0->2.0	2.0	4	<2.0->2.0	2.0	3	<2.0	<2.0
Total nitrite + nitrate	5	<2.0-12	5.8	5	<2.0-15	7.3	6	6.6-42	16	5	<2.0-7.4	4.4
Total phosphorus	5	220-1,200	450	5	160-300	206	6	180-450	327	5	120-250	202
Total inorganic carbon	5	<100-700	240	5	<100-200	120	6	<100-800	380	5	<100-200	140
Total carbon	5	13,000-25,000	2,080	5	11,000-14,000	12,000	6	29,000-55,000	45,000	5	9,800-17,000	12,500
Calcium	3	30-110	67	3	30-40	33	4	70-120	90	3	30-40	37
Magnesium	3	20	20	3	10-20	17	4	30-50	43	3	20-40	33
Sodium	3	<10	<10	3	<10	<10	4	<10	<10	3	<10	<10
Potassium	3	690-800	763	3	460-640	533	4	500-1,400	950	3	310-420	347

[a] N = number of samples.

Metals. The ranges and median concentrations of metals at the four sites are presented in Table 4-15. Cadmium was the only metal which was consistently at the detection limit. For most metals, the concentrations were similar at the two residential sites and the industrial site and considerably higher at the commercial site. This difference may be due to the fact that the commercial site is the only one of the four sites that receives regular street sweeping. The residual material after sweeping is the finer particles, which have more surface area per weight allowing them to adsorb more contaminants. Concentrations at the multiple-family residential site were generally lower than the other sites. The concentrations of metals in street particulates were generally an order of magnitude lower than the concentrations in dry deposition; however, the quantity of street particulate material greatly exceeded the amount of dry deposition material.

Organics. The street particulate samples were analyzed for 25 organic constituents. As shown in Table 4-16, the concentrations of 14 of these constituents were generally below the analytical detection limits. The highest concentrations of many of the remaining organics were found at the commercial site, and the lowest concentrations were found at the industrial site. The concentrations of organics were generally quite low in runoff from the commercial site. The higher concentrations in the street particulate material at the commercial site may be related to the routine street sweeping that this drainage area receives. The routine street sweeping tends to pick up the larger sediment particles and leave the smaller particles. The smaller particles tend to have more organics per unit weight (ug/kg) than the larger particles. Since the other drainage areas are not routinely swept, the samples collected in this study were a mixture of large and small particles, so the organics content was lower on a unit weight basis. Only 6 organic constituents exceeded the detection limit in dry deposition samples, whereas 11 constituents were found in street particulates at concentrations greater than the detection limits. With the exception of methoxychlor, the concentrations in dry deposition were considerably larger than the concentrations in street particulates; however, the quantity of street particulate material greatly exceeded the amount of dry deposition material. All pesticides detected in street particulates were also detected in rainfall and runoff.

Dry Weather Runoff

On September 3, 1982, USGS collected grab samples of dry weather runoff from the single-family and multiple-family residential sites. The dry weather concentrations of several conventional, metal, and organic constituents are compared to the mean wet weather runoff concentrations in Table 4-17.

Table 4-15. Ranges and Median Concentrations of Metals in Street Particulates

Constituent	Total recoverable metal concentration, ug/g											
	Single-family residential			Multiple-family residential			Commercial			Industrial		
	N[a]	Range	Median	N[a]	Range	Median	N[a]	Range	Median	N[a]	Range	Median
Priority pollutant metals												
Arsenic[b]	5	2.0–3.0	2.0	5	1.0–2.0	2.0	6	1.0–7.0	4.0	5	2.0–4.0	3.0
Cadmium	3	<1.0–<10	<1.0	3	<1.0–<10	<1.0	4	1.0–<10	2.0	3	<1.0–<10	1.0
Chromium	3	4.0	4.0	3	3.0–4.0	3.0	4	20	20	3	10–30	10
Copper	5	<10–18	12	5	5.0–17	10	6	12–50	34	5	27–54	40
Lead	5	500–790	562	5	200–430	400	6	280–1,000	770	5	100–300	150
Mercury	5	0.01–0.05	0.03	5	0.02–0.04	0.03	6	0.05–0.13	0.07	5	0.01–0.03	0.02
Nickel	5	<10–<100	10	5	8.0–<100	<10	6	10–<100	26	5	20–<100	20
Zinc	5	59–300	85	5	40–150	49	6	130–1,300	240	5	49–120	70
Other metals												
Aluminum	2	1,100–1,400	1,250	2	720–1,700	1,210	2	1,200–1,900	1,550	2	780–830	805
Iron	5	2,100–3,600	3,200	5	1,200–3,000	2,400	6	2,500–7,000	5,000	5	2,000–3,700	2,300
Manganese	2	43–65	54	2	31–60	46	2	61–110	86	2	34–46	40

[a] N = number of samples.
[b] Total arsenic.

Table 4-16. Ranges and Median Concentrations of Organics in Street Particulates

Constituent	Concentration, ug/kg											
	Single-family residential			Multiple-family residential			Commercial			Industrial		
	N[a]	Range	Median	N[a]	Range	Median	N[a]	Range	Median	N[a]	Range	Median
Priority pollutant organics												
Aldrin	5	<0.50–<1.0	<1.0	5	<0.50–<1.0	<0.5	3	<0.50–<4.0	<1.0	5	<0.50–<4.0	<1.0
Chlordane	5	170–470	290	5	57–160	110	3	280–3,400	420	5	69–260	110
DDD	5	<0.50–<4.0	<1.0	5	<0.20–<1.0	<0.50	3	<1.0–7.9	<4.0	5	<0.50–<4.0	<0.50
DDE	5	3.3–11	6.0	5	3.1–10	4.5	3	<0.50–<4.0	<1.0	5	8.1–15	12
DDT	5	11–31	15	5	<0.50–15	4.4	3	<1.0–19	3.3	5	7.4–33	21
Dieldrin	5	0.70–5.2	3.7	5	0.30–2.8	1.2	3	1.2–89	6.8	5	0.20–2.3	1.2
Endosulfan	5	<0.50–<4.0	<1.0	5	<0.20–6.7	<0.50	3	<0.50–<4.0	<1.0	5	<0.50–<4.0	<0.50
Endrin	5	<0.50–<1.0	<1.0	5	<0.10–<1.0	<0.50	3	<0.50–<4.0	<1.0	5	<0.50–<1.0	<0.50
Heptachlor epoxide	5	<0.50–1.2	<1.0	5	<0.10–2.2	<0.50	3	2.4–35	9.9	5	<0.50–2.8	<0.50
Heptachlor	5	1.0–2.2	1.4	5	<0.80–1.9	1.2	3	0.70–3.0	2.2	5	0.20–<4.0	<0.50
Lindane	5	1.5–26	2.8	5	0.60–3.3	1.5	3	1.7–4.8	4.1	5	2.0–4.6	2.1
PCB	5	10–51	13	5	30–49	38	3	220–860	820	5	23–37	33
Toxaphene	5	<50–<400	<100	5	<20–<100	<50	3	<50–<400	<100	5	<50–<400	<50
Other organics												
Diazinon	5	3.0–18	6.0	5	1.8–25	3.9	3	16–80	26	5	<0.10–20	<1.0
Ethion	5	<0.10–<1.0	<1.0	5	<0.10–<1.0	<0.10	3	<0.10–<1.0	<1.0	5	<0.10–<1.0	<1.0
Malathion	5	<1.0–10	2.9	5	<0.10–8.7	2.1	3	4.4–17	15	5	<0.10–2.1	<1.0
Methoxychlor	5	<0.50–<8.0	<1.0	5	<0.50–<8.0	<2.5	3	<0.50–<8.0	<1.0	5	<0.50–<8.0	<2.5
Methyl parathion	5	<0.10–<1.0	<1.0	5	<0.10–<1.0	<0.10	3	<0.10–<1.0	<1.0	5	<0.10–<1.0	<1.0
Methyl trithion	5	<0.10–<1.0	<1.0	5	<0.10–<1.0	<0.10	3	<0.10–<1.0	<1.0	5	<0.10–<1.0	<1.0
Mirex	5	<0.50–<1.0	<1.0	5	<0.50–<1.0	<0.50	3	<0.50–<4.0	<1.0	5	<0.50–<4.0	<1.0
Parathion	5	<0.10–29	<1.0	5	<0.10–36	1.0	3	<0.10–38	<1.0	5	<0.10–16	<1.0
Polychlorinated napthalenes	2	<10	<10	2	<5.0	<5.0	0	–	–	2	<10	<10
Perthane	5	<5.0–<40	<10	5	<2.0–<10	<5.0	3	<5.0–<40	<10	5	<5.0–<40	<5.0
Trithion	5	<0.10–<1.0	<1.0	5	<0.10–<1.0	<0.10	3	<0.10–<1.0	<1.0	5	<0.10–<1.0	<1.0
2,4-D	2	<0.50	<0.50	2	<0.50	<0.50	2	<0.50	<0.50	2	<0.50	<0.50

[a] N = number of samples.

Table 4-17. Comparison of Wet and Dry Weather Runoff Concentrations of Conventional Constituents, Metals, and Organics

Constituent	Units	Mean concentration			
		Single-family residential		Multiple-family residential	
		Wet	Dry	Wet	Dry
Specific conductance	umhos/cm	56	266	66	291
Dissolved nitrate	mg/l as N	0.75	0.93	0.89	1.5
Total phosphorus	mg/l as P	0.63	1.0	0.81	0.45
Dissolved calcium	mg/l	5.8	21	8.3	22
Dissolved chloride	mg/l	3.4	18	5.1	10
Arsenic	ug/l	2.1	4.0	2.7	6.0
Cadmium	ug/l	1.5	<1.0	1.5	1.0
Chromium	ug/l	9.3	2.0	16	4.0
Copper	ug/l	32	13	39	11
Lead	ug/l	353	93	225	6.0
Mercury	ug/l	0.60	0.10	0.33	0.10
Nickel	ug/l	14	12	40	12
Zinc	ug/l	211	70	290	20
Iron	ug/l	4,594	2,000	10,877	540
Chlordane	ug/l	0.16	0.10	0.25	<0.10
Lindane	ug/l	0.03	0.03	0.01	0.01
Diazinon	ug/l	0.36	1.1	0.70	2.1
Malathion	ug/l	2.2	5.7	1.3	2.1
Parathion	ug/l	0.21	<0.01	0.20	<0.01
2,4-D	ug/l	0.26	0.04	0.36	0.20

The dry weather concentrations of all of the conventional constituents except total phosphorus were greater than the wet weather concentrations. With the exception of arsenic, the wet weather concentrations of metals were greater than the dry weather concentrations. This may be due to the fact that metals adsorb to sediment particles, and wet weather storms are able to suspend sediment particles that are not moved by dry weather runoff. The concentrations of chlordane, parathion, and 2,4-D were greater in the wet weather samples and the concentrations of diazinon and malathion were greater in the dry weather samples. Diazinon and malathion are pesticides which are commonly used by homeowners.

Imported Recharge Water

The conventional constituent data collected by USDA on the quality of imported canal water used for recharge in Basins MM and EE are presented in Table 4-18. The data from samples collected from the canals show that the imported water is of excellent quality. All of the major anions and cations were found at low concentrations. Table 4-19 presents the concentrations of metals in the one sample that was collected. All of the metals concentrations are considerably lower than the concentrations in runoff. One sample was analyzed for 28 organic constituents. The concentrations were all less than the analytical detection limits, which ranged from 0.01 to 0.10 ug/l.

EPA Metals and Organics

The EPA conducted a supplemental analysis on several samples collected by USGS. Two grab samples were collected from each land use type on January 4, 1982, and analyzed for metals. Four samples were collected in March 1982 and analyzed for all of the priority pollutant metals and organics. Most of the organics were found at levels near or below the analytical detection limits. Table 4-20 presents the median concentrations of metals that were sampled by EPA but not sampled by USGS. The EPA analytical detection limits were much higher than the USGS limits, so most of the metals concentrations are reported as less than the detection limit. The concentrations of barium, boron, strontium, and titanium exceeded the detection limits. The highest concentrations of these four metals were found at the industrial site. The concentrations at the other three sites were similar. The concentrations of most of the priority pollutant organics were less than the detection limits of 1 to 25 ug/l.

ANALYSIS

The concentrations of various constituents measured in the runoff monitoring program were presented in the previous section of this chapter. Variations in the concentrations of key constituents during storm events and over the rain season are described in this section. The annual runoff and rainfall loads and unit runoff load factors for each land use type are also presented.

Water Quality Variations with Time

An analysis of the data collected in the Fresno NURP project showed that the runoff concentrations of many constituents varied during the storm events and seasonally.

Table 4-18. Concentrations of Conventional Constituents in Imported Recharge Water

Constituent	Units	Concentration[a] Basin MM	Basin EE
Specific conductance	umhos/cm	35.6	31.9
pH	Standard units	6.6	7.7
Turbidity	NTU	2.8	3.0
Suspended solids	mg/l	5.2	3.3
Calcium	mg/l	1.6	1.9
Magnesium	mg/l	0.20	0.20
Sodium	mg/l	1.0	1.1
Potassium	mg/l	0.13	0.13
Carbonate	mg/l	0	0
Bicarbonate	mg/l	25	24
Sulfate	mg/l	3.7	4.0
Chloride	mg/l	2.3	2.2
Nitrate	mg/l as N	0	0

[a] Mean concentrations of 24 samples are shown for specific conductance, turbidity, and suspended solids. All other concentrations are based on one sample collected on July 15, 1982.

Table 4-19. Concentrations of Metals in Imported Recharge Water

Constituent	Concentration, ug/l
Arsenic	<1
Cadmium	<1
Chromium	4
Copper	2
Iron	160
Lead	1.0
Mercury	0.1
Nickel	3.0
Zinc	10

Table 4-20. Median Concentrations of Metals Analyzed by EPA

Constituent	Total recoverable metal--median concentration, ug/l			
	Single-family residential	Multiple-family residential	Commercial	Industrial
Priority pollutant metals				
Antimony	<5	<5	<5	8
Beryllium	<1	<1	<1	<1
Selenium	<25	<25	<25	<25
Silver	<0.5	<0.5	<0.5	<0.5
Thallium	<10	<10	<10	<10
Other metals				
Barium	15	35	20	160
Boron	20	25	15	150
Cobalt	<10	<10	<10	10
Lithium	<10	<10	<10	15
Molybdenum	<10	<10	10	<10
Strontium	15	25	15	175
Tin	<50	<50	<50	<50
Titanium	70	230	65	790
Vanadium	<10	10	<10	35
Yttrium	<10	<10	<10	<10

Storm Event Variations. The USGS collected discrete grab samples during a number of storms monitored during the two years of the project. The number of samples analyzed varied from 2 to 17 depending on the length of the storm, and averaged about 5. The concentrations of most constituents were higher in the initial runoff samples than in samples collected later in the storms at the residential and commercial sites. Pollutants that have collected in the drainage area since the previous storm are washed off by the initial storm runoff. Therefore, the initial runoff results in high constituent concentrations because of the low runoff volumes that transport the collected constituents.

Constituent concentrations vary differently during a runoff event depending upon the type of constituent. Figures 4-2 and 4-3 show the concentrations of several key constituents at the multiple-family residential and commercial sites during several storms. Nutrient concentrations are generally highest at the beginning of storm runoff and then steadily decrease throughout the storm, independent of flow variations. Chemical oxygen demand (COD), biochemical oxygen demand (BOD), and specific conductance show the same pattern as nutrients. Metal concentrations are also generally higher at the beginning of runoff, but vary thereafter depending on velocity. This is probably due to the adsorption of metals to sediment particles. Larger sediment particles are moved by higher velocities; therefore, higher metal concentrations are generally found on the rising limb of a hydrograph.

There was no definite pattern in constituent concentrations at the industrial site during a storm. Figure 4-4 shows typical constituent concentrations throughout a storm at this site. The highest dissolved phosphorus and COD concentrations unexpectedly occur in the middle of the hydrograph and are not associated with a peak flow. Numerous specific conductance spikes were recorded at the industrial site during the study period, the largest of which occurred October 25, 1982, when the specific conductance rose from 666 umhos/cm to 9,960 umhos/cm in 8 minutes, and then receded to 1,025 umhos/cm 24 minutes later. These types of random concentration spikes were very common at this site.

Rain Season Variations. To determine if there were any seasonal variations in constituent concentrations, the USGS related the event mean concentration (EMC) of various constituents at each land use sampling site to the time in days since the first storm of the rain season. These relationships for various constituents are shown on Figure 4-5. The highest EMCs occur during the first two or three storms of the year and then become almost constant for the remainder of the rain season at the residential and commercial sites. This indicates

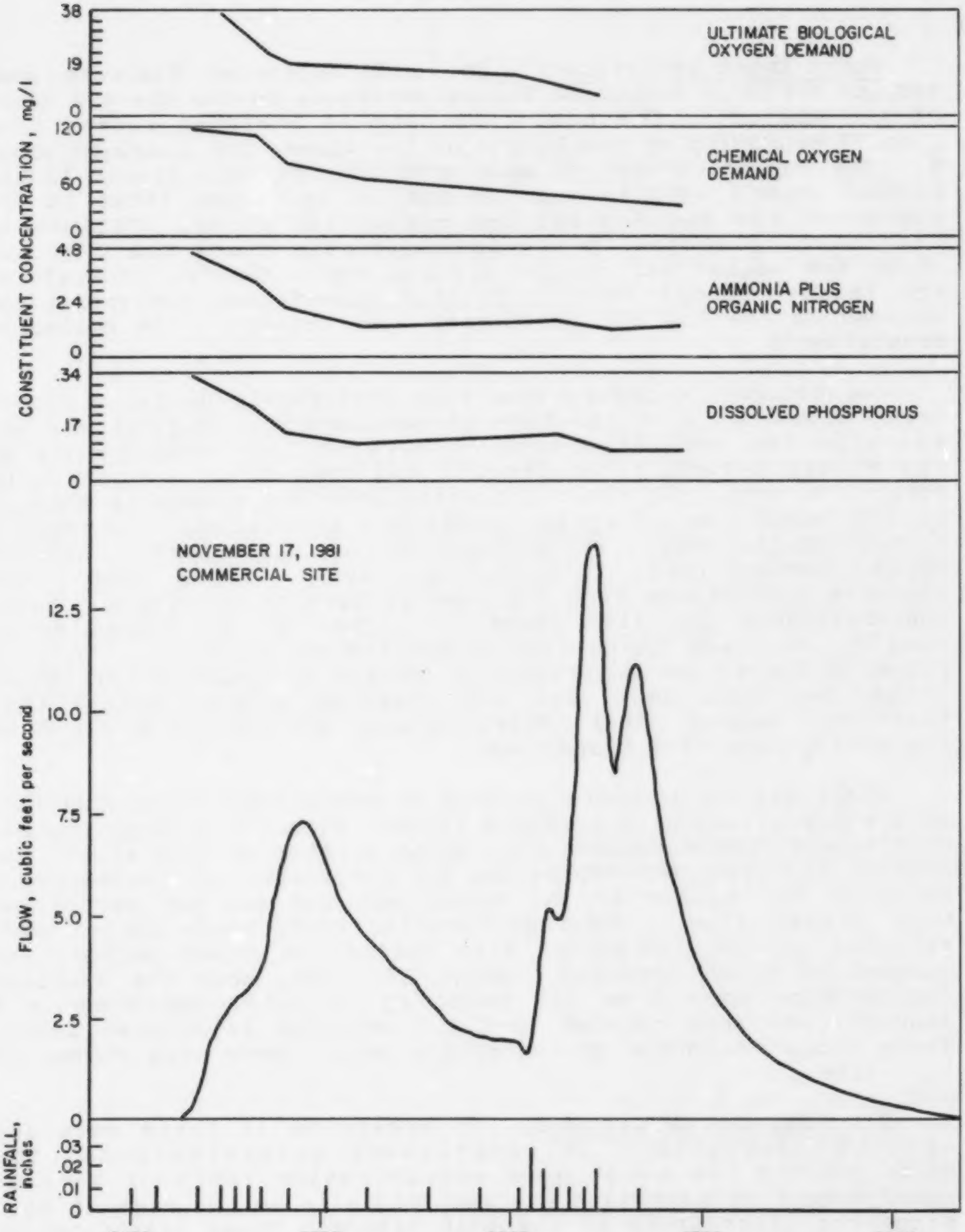


Figure 4-2 Water Quality Variations in Conventional Constituents During a Storm

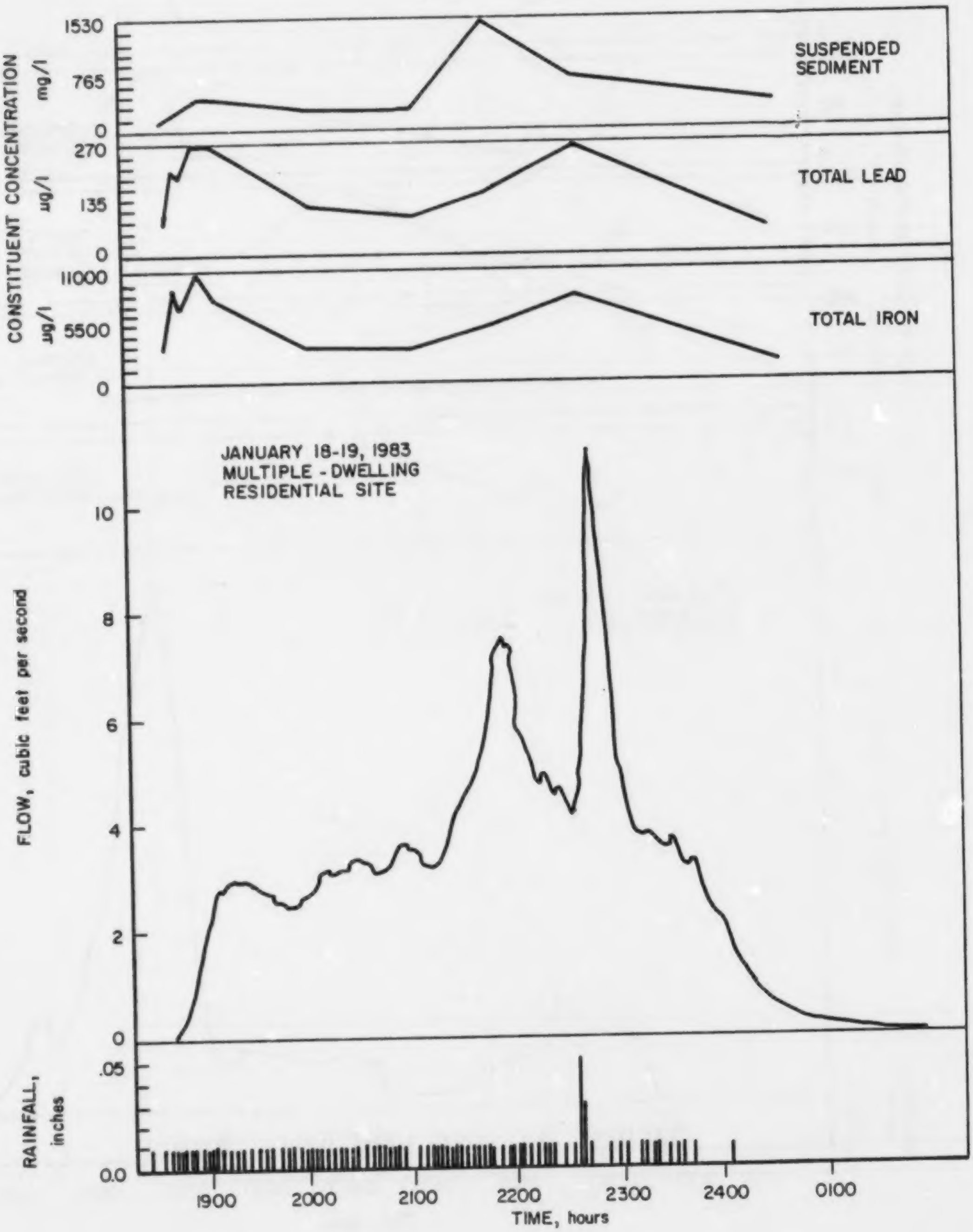


Figure 4-3 Water Quality Variations in Suspended Sediment and Metals During a Storm

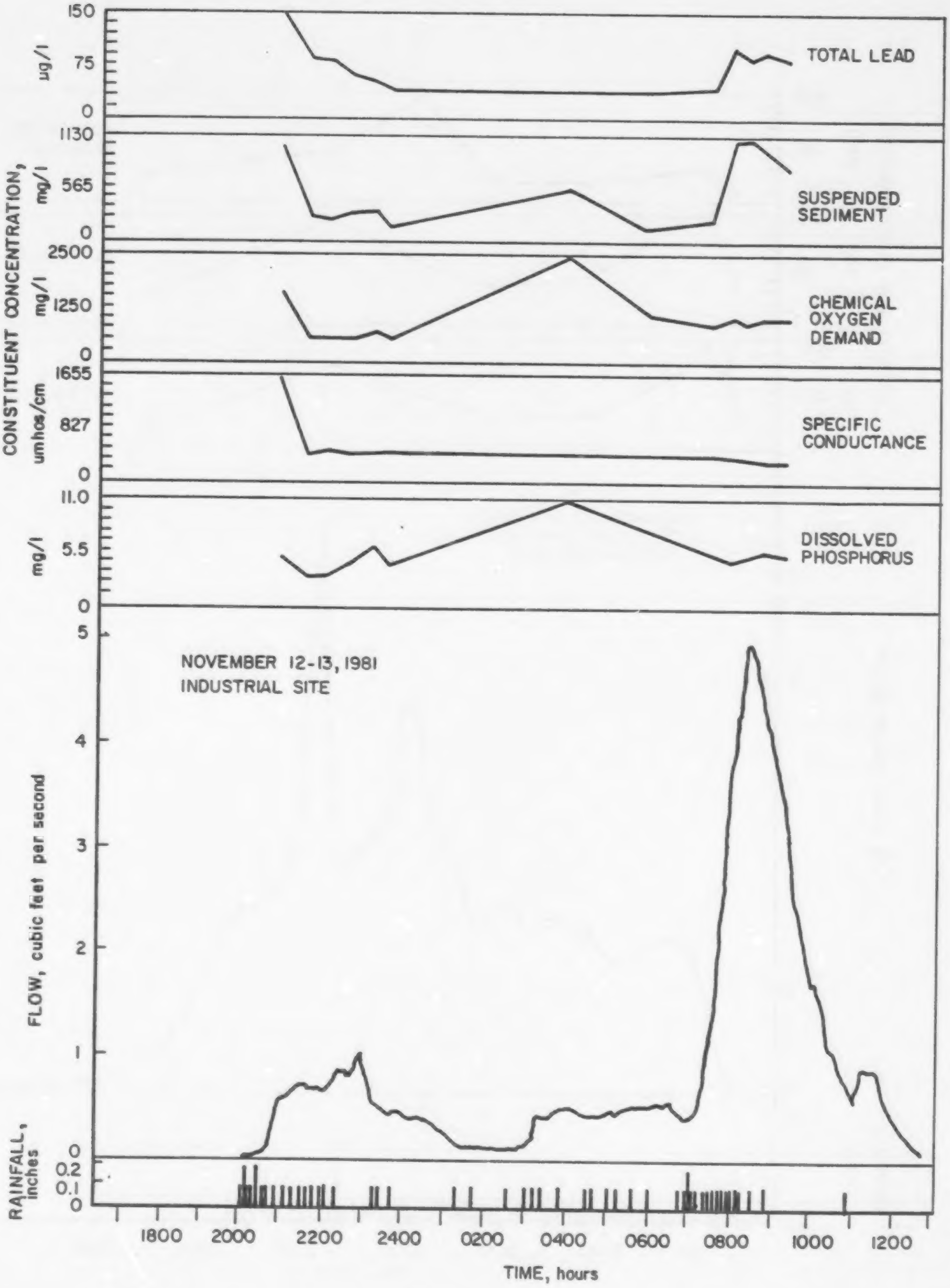


Figure 4-4 Water Quality Variations at the Industrial Site During a Storm

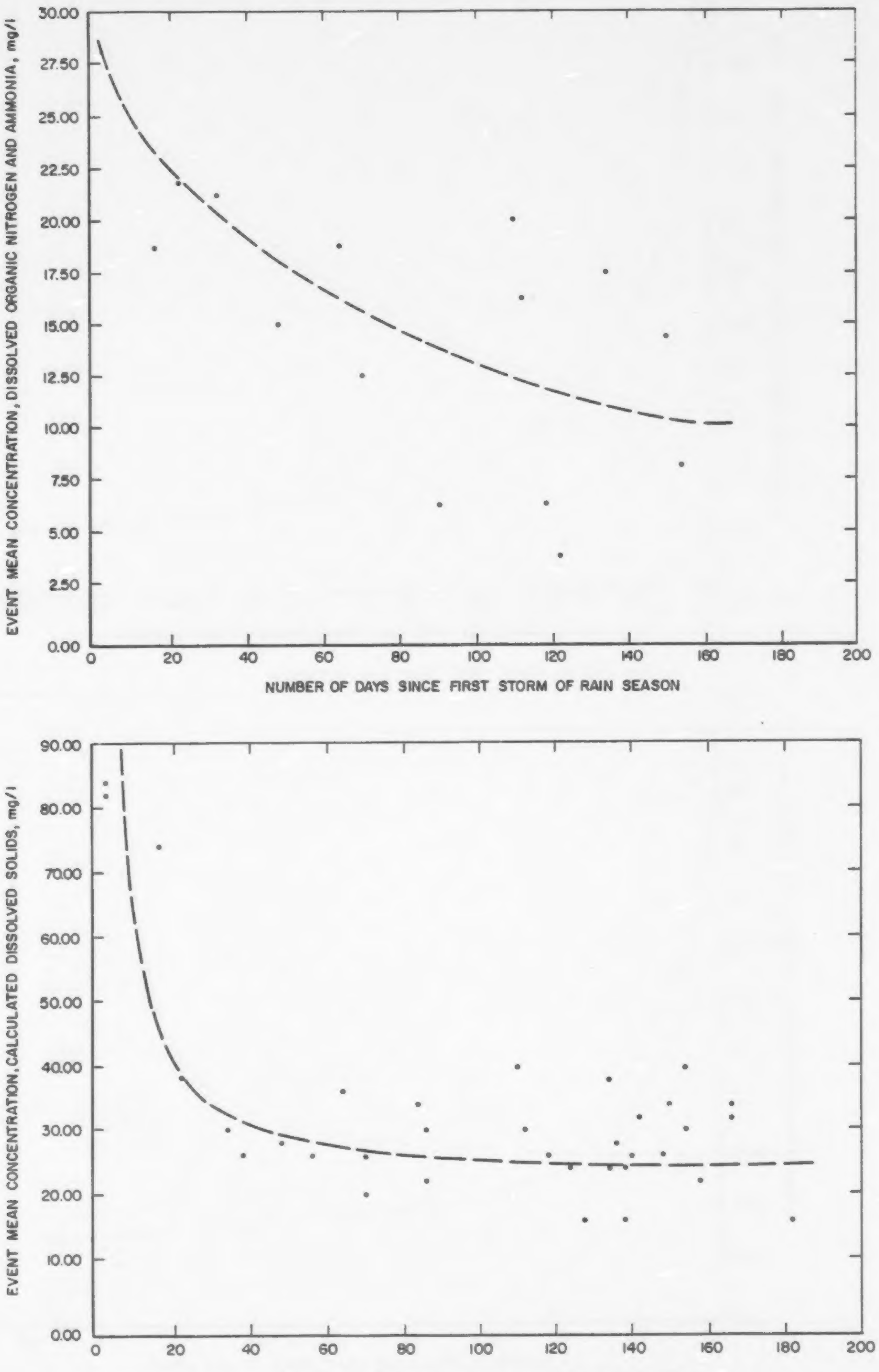
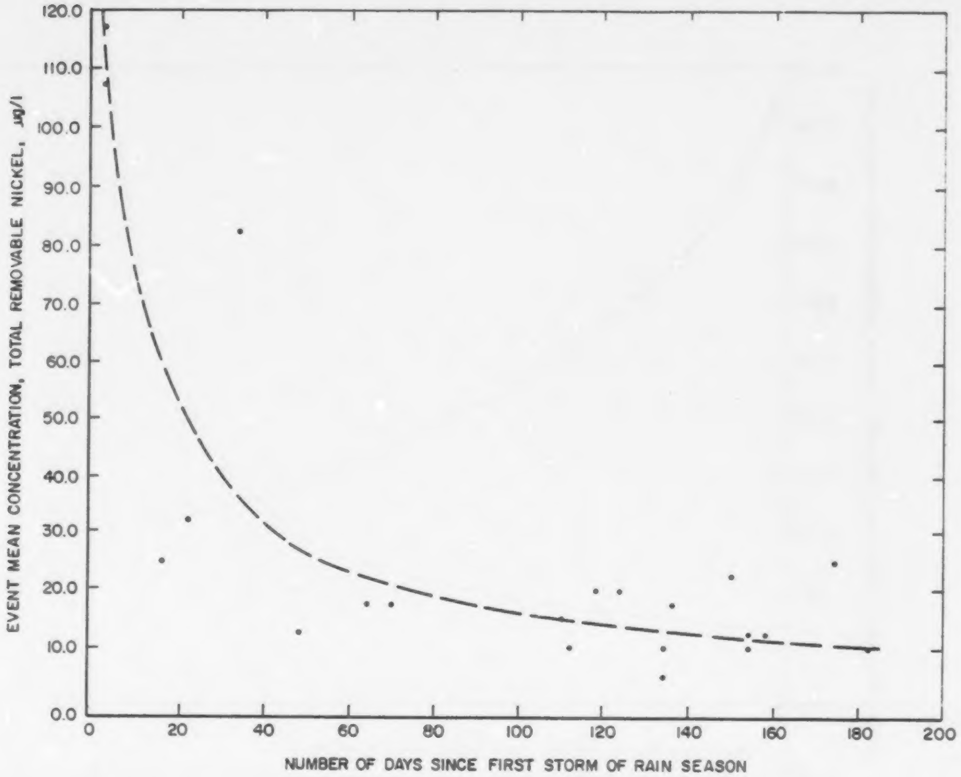


Figure 4-5 Relationships Between Event Mean Concentrations and Number of Days Since the First Storm of the Season



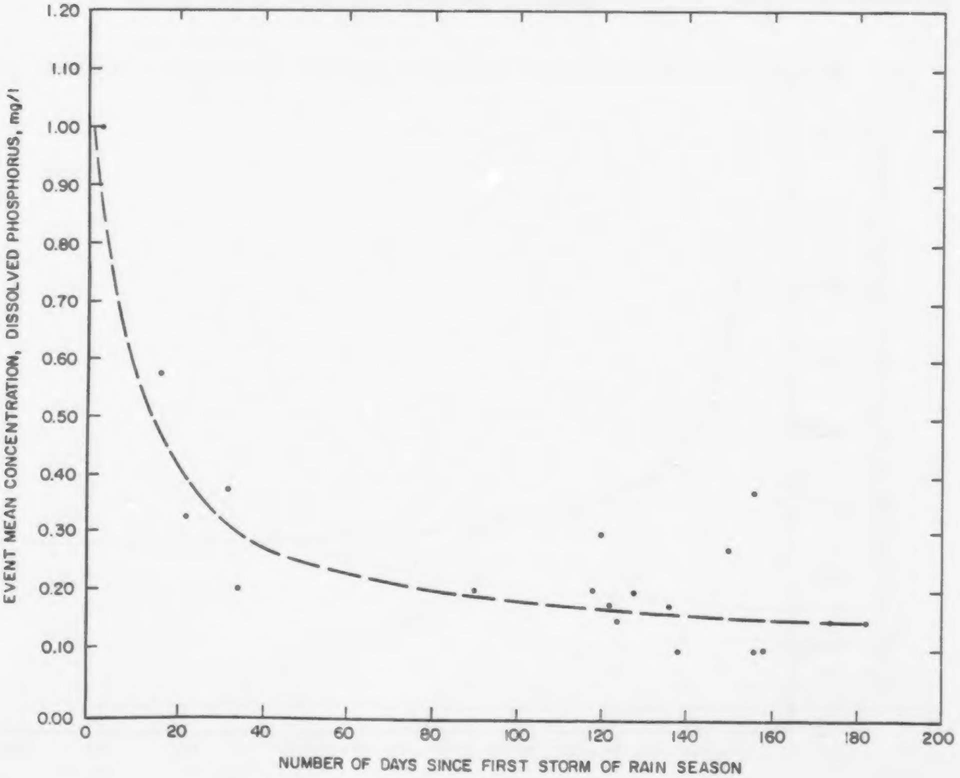


Figure 4-5 Relationships Between Event Mean Concentrations and Number of Days Since the First Storm of the Season (continued)

that at least two or three storms are necessary to wash off the pollutants that have accumulated in the drainage area throughout the dry months (usually May through September). Some constituent EMCs for the industrial catchment tend to decline uniformly throughout the entire rain season while other constituents showed no pattern at all. The constituent EMCs which did not show any pattern with the time since the first storm of the rain season at any of the land use types include dissolved and suspended organic carbon, total recoverable chromium, arsenic, and mercury. The remaining metal EMCs also did not show any pattern for the commercial and industrial catchments.

After this early rain season wash off, the EMC is influenced by the number of dry hours since the last storm and the storm runoff volume. Immediately after a storm, the drainage area begins accumulating atmospheric dry deposition along with vehicular deposition and other sources of constituents. Therefore, the longer the time since the last storm, the more material available to be washed off.

Upon wash off, the volume of runoff influences the constituent EMCs. If a small storm occurs and only washes off a part of the accumulated pollutants, the EMC will be higher than if a large storm occurs washing off all the available pollutants because of a greater degree of dilution. This is particularly true in the case of a highly impervious drainage area such as the commercial site where the pollutants are rapidly washed off, and as the storm progresses, the constituent concentrations approach the concentrations of the rain.

Annual Loads

Based on data collected by USGS, it was possible to determine the annual loads of several key constituents in rainfall and runoff. Key constituents are those constituents which were detected in soil or groundwater or are of concern in drinking water. The loads are based on a large amount of data collected during two wet seasons, 1981-82 and 1982-83. The rainfall during the 1981-82 season was 10.79 inches, which is 110 percent of normal. This rain season was not entirely normal since 40 percent of the rain fell in one month. The rainfall during the 1982-83 season was 23.56 inches, which is 240 percent of normal. The annual loads calculated for the 1981-82 season are, therefore, more representative of normal annual loads. The loads from dry deposition are based on less data and are not as accurate due to problems in gathering dry deposition data. It was not possible to calculate loads from street particulates. The methods used to calculate the loads are presented in this section. The loads are presented later in this chapter in the quasi mass balance section.

Rainfall. The annual loads of several key constituents in precipitation were calculated by determining the average EMC for each year at each site and then multiplying the EMC by the amount of rainfall in each year and by the drainage area of the single-family and industrial catchments. Since a single precipitation sample was collected over the duration of a storm, the concentration measured in this "composite" sample is considered the EMC for that storm. The average annual EMC is the mean of the individual storm EMCs. The loads of several constituents were calculated on a "flow-weighted" basis. The individual storm EMCs were weighted by the amount of precipitation that occurred. The flow-weighted loads were similar to the other loads.

Storm Runoff. The average EMC for each year was calculated to determine the annual loads from storm runoff. An EMC was calculated for each storm. For many storms, several discrete samples were collected and analyzed. For these storms, runoff loads were calculated and the EMC was determined by dividing the total storm load by the total storm runoff volume. During other storms, flow-weighted discrete samples were composited and analyzed as one sample. The EMC was equal to the concentration of that sample.

The annual runoff loads were calculated by determining the arithmetic average EMC for each year and multiplying it by the amount of precipitation, the drainage area of each land use catchment, and the flow-weighted runoff coefficients of each land use. The loads of several key constituents were calculated on a "flow-weighted" basis. The annual average EMC was calculated by weighting the individual storm EMCs by the amount of runoff that occurred in the storm. The arithmetic mean and flow-weighted loads are compared later in this chapter.

Dry Deposition. As discussed in the USGS report, it is extremely difficult to collect accurate dry deposition data. Extrapolating a limited amount of data collected at one site to the entire drainage area is questionable; however, it does allow a comparison of the dry deposition loads to the loads from other sources. The nutrient and metal loads are based on nine samples and the organic loads are based on one sample.

Street Particulate Material. It was not possible to calculate annual loads of constituents collected on street surfaces due to problems in collecting the data. According to USGS, the 20 to 25 curb-to-curb samples that were collected for each drainage area represent only about 0.1 percent of the street surface area in the drainage area. The multiple-dwelling residential and industrial drainage areas often had sand and silt deposits in the gutters due to erosion from adjacent slopes. When this material was accidentally collected along with the sample, it heavily influenced the results. Due to these types of problems, street particulate loads were not calculated.

Quasi-Mass Balance. To determine the relative contributions of rain and dry deposition to runoff, a mass balance of several key constituents was calculated. Table 4-21 presents the annual loads of several key constituents from runoff, precipitation, and dry deposition at the single-family residential and industrial sites. The average loads using both years of data are shown for the conventional constituents. Since less data were collected on the metals and organics, it was only possible to show the loads from 1982-83. The actual pollutant loads from precipitation were multiplied by the flow-weighted runoff coefficients for the single-family residential site and the industrial site, since these coefficients represent the proportion of rainfall that runs off the drainage area at the runoff sampling sites. The remaining rainfall and the associated pollutant load never reach the runoff sampling site. The following runoff coefficients were used:

Conventional constituents (1981-82 and 1982-83)	
Single-family residential	0.24
Industrial	0.23
Metals and organics (1982-83)	
Single-family residential	0.25
Industrial	0.23

There is no rigorous method for estimating the amount of dry deposition that ends up in runoff. The amount of dry deposition that is picked up by runoff and carried to a recharge basin is dependent on rain intensity and the scouring velocity of the runoff water, as well as the type of ground surface. For purposes of this balance, the runoff coefficients used to estimate the portion of rainfall that runs off the drainage area were also used for estimating the portion of dry deposition that ends up in runoff.

The pollutant loads from rainfall and dry deposition should be less than the pollutant loads in runoff. This is because there are other sources of these pollutants in the drainage area which could not be quantified. For example, cars contribute metals, particularly lead, to the drainage areas. Homeowners contribute pesticides to the drainage area when they spray lawns and gardens. Animal wastes and fertilizer contribute nutrients to the drainage areas. As shown in Table 4-21, the runoff loads of many constituents at

Table 4-21. Mass Balance of Contaminant Sources to Urban Runoff

Constituent	Loads, lbs/year per drainage area[a]							
	Single-family residential				Industrial			
	Rainfall[b]	Dry deposition[b]	Atmospheric total	Runoff	Rainfall[b]	Dry deposition[b]	Atmospheric total	Runoff
Dissolved nitrate + nitrite	19	160	180	86	63	170	230	600
Total phosphorus	1	9	10	78	23	87	110	1,700
Dissolved calcium	43	85	130	400	140	200	340	4,500
Dissolved chloride	43	53	96	160	130	150	280	44,000
Arsenic[c]	0.14	0.10	0.24	0.19	0.36	0.20	0.56	3.6
Chromium[c]	0.14	0.50	0.64	0.70	0.36	2.7	3.1	4.0
Copper[c]	0.48	3.0	3.5	1.1	2.9	6.9	9.8	17
Lead	1.1	9.1	10.2	21	3.9	10.4	14.3	21
Mercury[c]	0.014	0.018	0.032	0.13	0.045	0.037	0.082	0.20
Iron[c]	44	95	139	518	240	341	581	3,389
Manganese[c]	2.3	2.5	4.8	13	9.6	10.1	19.7	119
Chlordane[c]	0.014	0.002	0.016	0.019	0.039	0.004	0.043	0.037
DDT[c]	0.001	0	0.001	0.001	0.004	0	0.044	0.004
Diazinon[c]	0.011	0.0007	0.012	0.037	0.043	0.003	0.046	0.23

[a] The characteristics of the single-family residential and industrial drainage areas are presented in Table 4-1.

[b] The annual rainfall and dry deposition loads were multiplied by the flow-weighted runoff coefficients for the single-family residential site and the industrial site to correct for the amount of pollutants that never reach the runoff sampling sites.

[c] Loads for these constituents are based on 1982-83 data only. Loads for all other constituents are the average load for 1981-82 and 1982-83.

the single-family residential site and most constituents at the industrial site were considerably higher than the sum of rainfall and dry deposition loads, indicating a significant contribution from other sources. Over 50 percent of the load of total phosphorus, calcium, mercury, iron, manganese, and diazinon at the single-family residential and industrial sites is from other sources. In addition, over 50 percent of the nitrate-nitrite, chloride, and arsenic loads at the industrial site are from other sources. The majority of the atmospheric load of most constituents came from dry deposition. The majority of the arsenic, chlordane, DDT, and diazinon loads came from rainfall; however, only one dry deposition sample was analyzed for organics so it is difficult to compare these data.

Although the mass balance is not precise, it does give a good indication of the relative sources of several key constituents. The mass balance is fairly good considering the problems involved in collecting dry deposition data and the fact that street particulate loads could not be included in it.

Unit Runoff Load Factors. Unit runoff loads in pounds per acre per year (lbs/acre/year) were calculated for the key constituents at each land use site. Although unit loads were not calculated for rainfall and dry deposition, it is possible to calculate these loads from the data presented in Table 4-21. The unit loads presented in Table 4-22 are based on the 1981-82 runoff loads, since 1981-82 was closer to a normal rainfall year in Fresno than was 1982-83. Some of the unit loads presented in Table 4-22 differ from those presented in the USGS report because they were calculated differently. The unit loads in the USGS report were based on loads from both years of the project and excluded some of the fall storms.

In general, the highest unit load factors were found at the commercial site and the lowest were found at the single-family residential site. The runoff load factors for suspended solids ranged from 51 lbs/acre/year at the single-family residential site to 280 lbs/acre/year at the industrial site. The high suspended solids factors at the multiple-family residential and industrial sites are probably due to erosion from vacant land in these two drainage areas. The unit loads of major ions and nutrients were all lowest at the single-family residential site and highest at the commercial and industrial sites. The unit loads of major ions and nutrients were generally less than 10 lbs/acre/year at all sites. The unit loads of metals were generally less than 0.1 lb/acre/year at all sites. The lowest metal unit loads were generally found at the single-family residential site and the highest unit loads were found at the commercial site. The unit loads of organics were generally less than 0.001 lb/acre/year at all sites.

Table 4-22. Annual Loads of Key Constituents in Runoff

Constituent	Load, lbs/year											
	Single-family residential			Multiple-family residential			Commercial			Industrial		
	1981-82	1982-83	Mean	1981-82	1982-83	Mean	1981-82	1982-83	Mean	1981-82	1982-83	Mean
Suspended solids	4,900	23,000	14,000	9,500	94,000	52,000	7,700	160,000	84,000	77,000	211,000	144,000
Dissolved solids	3,500	7,400	5,500	3,500	23,000	13,000	5,800	85,000	45,000	41,000	249,000	145,000
Dissolved nitrate + nitrite	42	130	86	35	270	150	120	1,200	660	190	1,000	600
Total phosphorus	46	110	78	23	190	110	59	300	180	1,100	2,200	1,700
Dissolved calcium	230	560	400	310	1,600	960	670	8,000	4,300	1,900	7,000	4,500
Dissolved chloride	93	230	160	200	920	560	440	2,800	1,600	5,700	83,000	44,000
Arsenic	0.10	0.19	0.15	0.12	0.30	0.21	0.42	1.6	1.0	3.5	3.6	3.6
Chromium	0.48	0.70	0.59	0.71	1.7	1.2	1.5	4.1	2.8	3.7	4.0	3.9
Copper	1.2	1.1	1.2	1.2	1.8	1.5	2.0	5.2	3.6	12	17	15
Lead	8.8	33	21	8.9	30	19	16	89	53	13	29	21
Mercury	0.005	0.13	0.066	0.017	0.039	0.028	0.026	0.049	0.038	0.041	0.20	0.12
Iron	80	518	299	361	1,668	1,015	167	2,726	1,447	1,835	3,389	2,612
Manganese	-	13	-	-	39	-	-	87	-	-	119	-
Chlordane	0.008	0.019	0.014	0.006	0.048	0.027	0.017	0.040	0.029	0.016	0.037	0.027
DDT	0.0005	0.001	0.0008	0.0004	0.002	0.001	0.001	0.003	0.002	0.001	0.004	0.003
Diazinon	0.025	0.037	0.031	0.062	0.058	0.06	0.11	0.66	0.39	0.15	0.23	0.19

A sensitivity analysis was conducted to determine if unit loads calculated from an arithmetic average EMC differed from loads calculated from a flow-weighted EMC. The 1981-82 data were used since the amount of precipitation during that year was more normal than during 1982-83. The loads of lead, copper, iron, and arsenic were calculated with both methods. The flow-weighted loads were calculated from a flow-weighted EMC. The EMC was determined by weighting the individual storm EMCs by the amount of runoff that occurred during the storm. The EMCs and unit loads calculated with both methods are shown in Table 4-23. Most of the flow-weighted unit loads at the single-family residential and commercial sites are 10 to 20 percent lower than the arithmetic unit loads. The exceptions are arsenic and lead at the single-family residential site. The lower flow-weighted loads are due to the occurrence of one large storm that had low concentrations of metals.

When the loads are calculated on a flow-weighted basis, this method significantly reduces the unit load factors. The flow-weighted unit loads at the multiple-family residential and industrial sites were 10 to 20 percent higher than the arithmetic unit loads. There were two large storms that had high metals concentrations at these sites. When the loads are calculated on a flow-weighted basis, these storms increase the unit load factors.

Table 4-23. Comparison of Arithmetic and Flow-Weighted EMCs and Loads

Land use/constituent	Arithmetic basis		Flow-weighted basis	
	EMC, ug/l	Unit load, lbs/acre/yr	EMC, ug/l	Unit load, lbs/acre/yr
Single-family residential				
Lead	170	0.092	100	0.054
Copper	22	0.013	16	0.009
Iron	1,538	0.83	1,225	0.66
Arsenic	2.0	0.0010	2.1	0.0011
Multiple-family residential				
Lead	212	0.20	245	0.23
Copper	29	0.027	32	0.030
Iron	8,616	8.0	10,072	9.4
Arsenic	2.8	0.0027	3.1	0.0030
Commercial				
Lead	103	0.28	90	0.24
Copper	13	0.034	12	0.031
Iron	1,091	2.9	951	2.5
Arsenic	2.7	0.0072	2.1	0.0056
Industrial				
Lead	86	0.047	99	0.054
Copper	72	0.044	77	0.047
Iron	11,396	6.7	14,173	8.3
Arsenic	21	0.013	23	0.014

CHAPTER 5

SOILS AND GROUNDWATER MONITORING PROGRAM

To evaluate the effect of recharging urban storm runoff, the soils and groundwater underlying several recharge basins were monitored. This portion of the Fresno Nationwide Urban Runoff Program (NURP) project was conducted by the U.S. Department of Agriculture (USDA), Agricultural Research Service's Water Management Research Unit in Fresno, California. Data gathered by USDA are presented and analyzed in this chapter. A more detailed presentation and statistical analysis of the data are contained in the project report prepared by USDA.

DESCRIPTION OF MONITORING PROGRAM

The field program consisted of sampling of four major components: soils, soil water, groundwater, and plant tissue. The investigation was conducted at five of the District's recharge basins. Test basin locations are shown on Figure 4-1. The principal characteristics of these basins are listed in Table 5-1. Samples were analyzed for a wide range of constituents, including physical properties, minerals, metals, and organics. A complete list of the constituents measured in this portion of the program is presented in Appendix B Detailed descriptions of the sampling programs are contained in the USDA project report. The programs are briefly described in this section.

Table 5-1. Key Characteristics of USDA Test Basins

Characteristic	Basin name				
	F	G	M	EE	MM
Size, acres	6.0	8.5	9.0	10.0	8.5
Depth, feet	9.0	6.0 to 8.0	10.0	29.0	21.0
Drainage area, acres	475	403	620	2,314	895
Storage capacity, cubic feet	1,768,500	1,546,400	4,310,300	8,716,400	5,131,900
Vegetation	Fully turfed	Fully turfed	Fully turfed	Unturfed	Unturfed
Availability of canal water for artificial recharge	Yes	No	No	Yes	Yes
Completion year	1965	1962	1969	1977	1978

Soils

Initial soils samples were collected at all five sites during the summer of 1981. Samples were then collected in the spring of 1982 and 1983 after each wet weather season. In addition, the basins that receive summer irrigation water for recharge were sampled at the end of the irrigation season in both 1982 and 1983. The technique for collecting soils samples varied with depth. The surface soil layer was sampled at several depths to a maximum of 0.3 meter (m) with a hand core sampler. The soil layer from the surface to 3 m was sampled every 0.3 m with a bucket auger. The soil layer from 3.0 m to the top of the water table was core sampled (0.8m long core) every 1.5 m with a hollow-stem flight auger. Soil samples were also collected at "uncontaminated" control sites near each test basin to determine background conditions. About 1,550 soil samples were collected for analysis.

Soil Water and Groundwater

Obtaining a suitable (0.5 to 1.5 liter) sample of percolating runoff water in the unsaturated zone is difficult under the best of subsurface stratification conditions. Vacuum ceramic-Teflon soil water extractors were used in this project. Extractors were placed on top of a soil layer known to have a lower hydraulic conductivity than the soil just above that layer. This was done with the hope that soil water would be more available in these locations than elsewhere in the unsaturated zone. Soil water was collected at two or three depths in each basin. The very top zone of the water table or deep perched water table was sampled in each basin since, if runoff pollutants are moving downward, they should most easily be detected at the top of the water table. The volume of water extracted from the soil in the unsaturated zone was variable and depended on soil physical properties and availability of water resulting from the recharge taking place. Water samples were collected on a bimonthly basis between January and September 1982, and on a monthly basis between October 1982 and July 1983. A total of 334 water samples were collected for chemical analysis.

Plant Tissue

Plant tissue samples were collected to evaluate the uptake of certain metals by vegetation covering the surface of some of the basins. Two locations were sampled within each of the three turfed basins. One location was in a deeper portion of the basin where pollutants tend to accumulate. The second was above the high-water line in an area that should not be directly affected by runoff water. Four sets of plant tissue samples were collected during the two-year study producing a total of 61 samples.

RESULTS

A summary of the results of the soils and groundwater monitoring program is presented in this section. All of the data are not presented, since this report focuses on the constituents that are most important in terms of the potential contamination of the water supply and the potential for health hazards associated with recreational activities within the basins. A more complete presentation and discussion of the data are contained in the USDA project report.

Soils

Soils data results are divided into three groups: physical properties, metals, and organics.

Physical Properties. The soil texture (sand, silt, and clay content) and cation exchange capacity help define the stratigraphy of each basin in relation to its recharge potential. Soil texture and cation exchange capacity profiles are presented on Figure 5-1. The upper half of each figure is for the 0-to-30-centimeter (cm) soil samples and the bottom half is the 0-to-3 m bucket auger samples, plus the flight auger cores below 3 m. There are significant variations among recharge capabilities of the five basins:

1. Basin F--The first 3 m of the profile is sandy followed by a silt loam layer from about 3 to 10.5 m, then a loamy sand layer to 15 m, followed by a second silt loam layer to 19.5 m, then into sandy loam and first zone of water saturation. Basin F has a profile that is fairly good for recharge in spite of the two silt loam layers.

2. Basin G--The major clay layer extends from 7.5 to 13 m and silty layer from 13 to 18 m. The soil profile for Basin G has a poorer recharge potential compared to Basin F because of the higher clay content.

3. Basin M--There is a sandy loam layer extending from about 4 to 9 m, but below this the soils are loamy sands. The soil profile for Basin M has greater recharge potential than Basins F and G.

4. Basin EE--There is a very tight clay layer extending from 1 to 3 m below the basin floor, which has the highest cation exchange capacity of any of the five main basins sampled. Below the clay layer there are some sands, but at 4.5 m there is a second clayey layer. Below about 6 m, the silt content increased. The first zone of saturation encountered was at 10 m below the

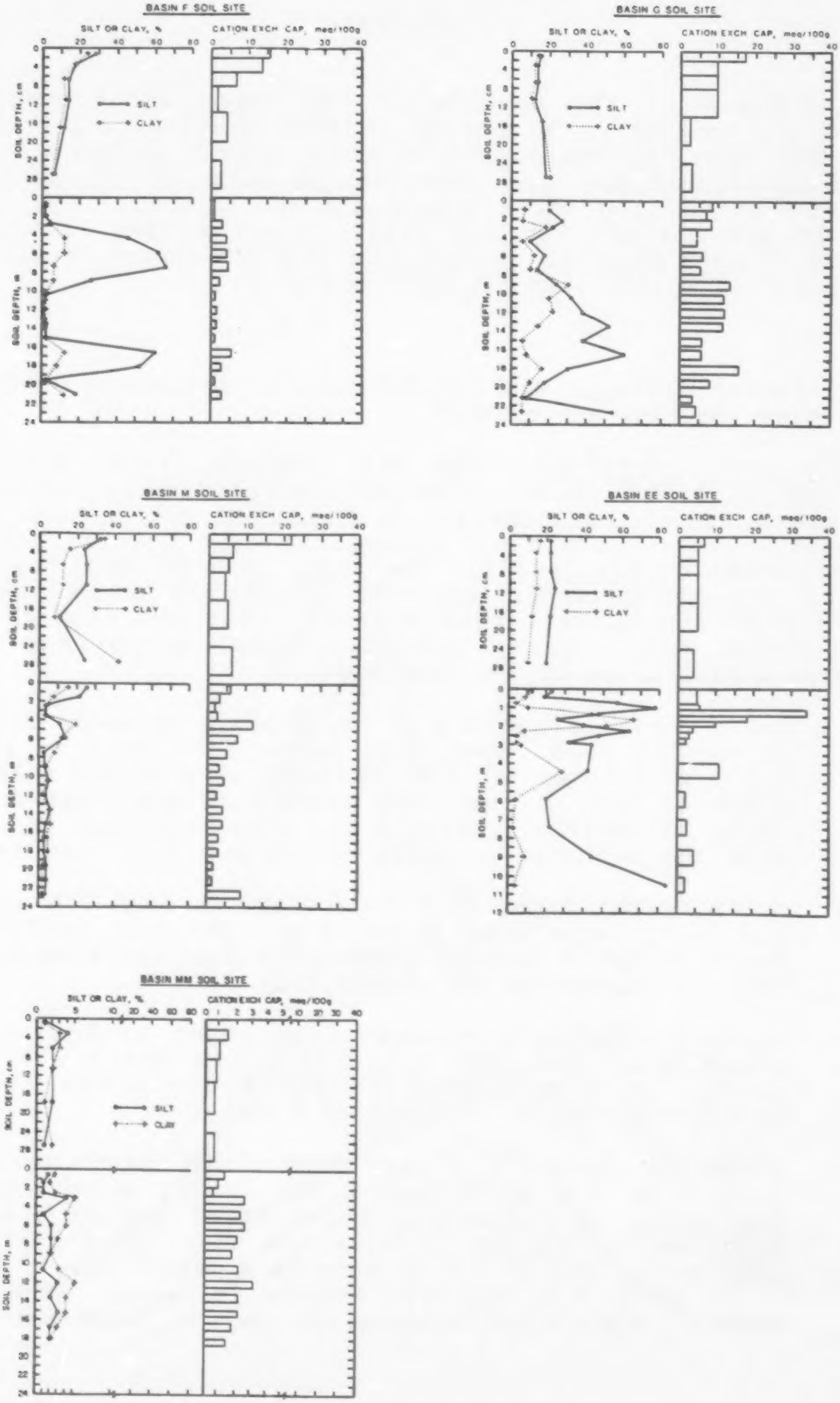


Figure 5-1 Silt, Clay, and Cation Exchange Capacity Profiles in Basin Soils

basin floor and is believed to be a perched water table. Basin EE has the poorest recharge potential of any of the five basins.

5. Basin MM--The entire soil profile is loamy sand to sands and consequently has the highest recharge potential of all the five basins.

Metals. The metals of primary interest in this study were nickel, copper, and lead. Arsenic was also included in this group. Concentrations of these elements detected in the soil underlying each test basin are listed in Table 5-2. The mean concentration of each metal for each soil horizon are presented and are based on three samplings: summer 1981, spring 1982, and spring 1983. Concentrations decrease rapidly with depth. For example, the maximum lead concentration of 1,600 milligrams/kilogram (mg/kg) was measured in the surface layer (0.00 to 0.02 m) of Basin M. However, within 0.14 m or about 6 inches, the lead concentrations had decreased to 15 mg/kg or less. There are some differences among the metal concentrations among basins. Concentrations tend to be highest in Basin M and lowest in Basin MM. Differences may be caused by several factors, including the type and amount of runoff received, soil properties, and whether the basin receives summer recharge water. Some of these factors will be analyzed later in this chapter and in Chapter 6.

The presence of mercury in basin soils was investigated with 1983 soil samples from Basins G and EE, after mercury was detected in several runoff samples. Mercury was detected within the upper 0.14 m of soil. The maximum concentrations were measured at the surface (0.00 to 0.02 m) and were 0.07 mg/kg and 0.10 mg/kg in Basins G and EE, respectively.

Organics. Soils samples were regularly tested for numerous specific organic compounds, including chlorinated pesticides, organophosphorus pesticides, chlorophenoxy herbicides, and phenolic compounds. Specific constituents for which analyses were conducted are listed in Appendix B. Several samples were also analyzed for semivolatile organics and purgeable organics by gas chromatography/mass spectrometry in accordance with Environmental Protection Agency (EPA) Methods 625 and 624. Specific constituents covered by these methods are also listed in Appendix B. Organics results are briefly described below.

1. Chlorinated pesticides--Only four of the chlorinated pesticides were detected in at least one soil sample. The most prevalent compound was chlordane, which was

Table 5-2. Mean Concentrations of Arsenic, Nickel, Copper, and Lead in Basin Soils

	Basin F				Basin G				Basin M			
	Mean concentration, mg/kg				Mean concentration, mg/kg				Mean concentration, mg/kg			
Depth, m	Arsenic	Nickel	Copper	Lead	Arsenic	Nickel	Copper	Lead	Arsenic	Nickel	Copper	Lead
0.00 to 0.02	20.0	32.0	37.0	713.0	7.4	37.0	25.0	487.0	31.0	53.0	55.0	1,333.0
0.02 to 0.05	16.0	26.0	27.0	370.0	9.9	37.0	19.0	467.0	5.8	20.0	16.0	283.0
0.05 to 0.08	10.0	16.0	9.2	73.0	8.8	37.0	15.0	184.0	6.7	14.0	11.0	37.0
0.08 to 0.14	7.8	15.0	7.3	27.0	7.2	33.0	16.0	39.0	6.1	13.0	8.7	22.0
0.14 to 0.20	4.4	15.0	5.2	17.0	4.3	29.0	15.0	26.0	4.3	13.0	7.4	7.2
0.24 to 0.30	2.3	9.1	3.8	13.0	6.3	30.0	9.5	7.5	6.9	16.0	8.1	10.0
0.30 to 0.60	2.3	7.3	5.3	3.6	7.2	71.0	11.0	9.1	10.0	19.0	8.3	9.1
0.90 to 1.20	1.5	8.0	4.5	2.8	9.2	37.0	14.0	5.2	6.4	16.0	9.5	4.6
1.50 to 1.80	1.4	6.0	4.8	2.4	3.0	22.0	12.0	4.0	6.7	17.0	7.6	4.6
2.10 to 2.40	1.7	6.8	5.3	2.8	3.5	18.0	7.8	4.3	4.9	13.0	7.6	3.7
2.70 to 3.00	1.7	5.7	2.1	2.8	10.0	87.0	21.0	5.3	2.2	9.1	6.5	2.4

	Basin EE				Basin MM			
	Mean concentration, mg/kg				Mean concentration, mg/kg			
Depth, m	Arsenic	Nickel	Copper	Lead	Arsenic	Nickel	Copper	Lead
0.00 to 0.02	4.8	22.0	25.0	297.0	4.5	11.0	9.5	93.0
0.02 to 0.05	6.4	16.0	20.0	250.0	3.5	8.6	5.8	34.0
0.05 to 0.08	4.7	13.0	15.0	160.0	1.8	5.4	2.0	12.0
0.08 to 0.14	3.6	11.0	7.7	87.0	2.4	6.6	1.9	4.5
0.14 to 0.20	4.1	9.8	5.8	11.0	2.3	6.2	1.4	2.5
0.24 to 0.30	2.2	10.0	6.7	3.4	2.3	4.2	1.8	1.7
0.30 to 0.60	11.0	11.0	5.6	4.8	2.1	6.0	2.1	4.3
0.90 to 1.20	7.6	11.0	8.6	5.4	1.9	4.9	1.5	1.9
1.50 to 1.80	11.0	14.0	17.0	7.2	1.2	4.3	1.8	2.1
2.10 to 2.40	4.7	10.0	6.2	3.0	2.9	6.6	2.7	2.0
2.70 to 3.00	3.1	10.0	5.5	2.2	2.9	7.3	3.0	1.9

consistently detected in all five basins. Table 5-3 indicates the concentration of chlordane found in the soil profile in 1981, 1982, and 1983. Chlordane was present in the highest concentrations in the surface soil of the older, turfed basins (F, G, and M). Maximum concentration detected was 2.7 mg/kg in Basins G and M in 1982. Concentrations rapidly decreased with depth and concentrations were generally less than detection limits within 24 cm (10 inches).

In addition, three other chlorinated organics were occasionally detected: lindane, DDT, and DDE. Table 5-4 lists the concentrations of these three compounds for samples when they were detected. Lindane was detected only in Basin F at concentrations between 0.01 and 0.02 mg/kg in a total of five samples, which were near the surface. DDT was detected at the surface in four of the five basins in a total of seven samples. DDE was detected in three of five basins in a total of ten samples. The maximum penetration of any of these three chlorinated organics was 0.20 m (8 inches).

2. Organophosphorus pesticides--The organophosphorus pesticides searched for in selected soil depth intervals from the surface to the first zone of saturation were: diazinon, ethion, malathion, methylparathion, and parathion. None of these pesticides were detected in any of the soil samples. Detection limit for these constituents was 0.003 mg/kg (or three parts per billion).

3. 2,4-D--Soil samples collected in 1982 were analyzed for the herbicide 2,4-D. The herbicide was not detected in any of the samples. Detection limit was 0.02 mg/kg.

4. Phenolic compounds--Total phenol was detected in the surface soils in several samples. Total phenol was detected in all five basins. The maximum concentration encountered was 0.17 mg/kg in Basin MM. Phenol concentrations decreased with depth and below 1.5 m concentrations were less than the detection limit of 0.005 mg/kg, except for Basin MM. Phenol was detected in sandy Basin MM down to 3 m. Specific phenols searched for were: pentachlorophenol, 2,4-dimethylphenol, 4-nitrophenol. These compounds were not detected in any of the soil samples.

5. Semivolatile and purgeable priority pollutants--Several samples were analyzed for the semivolatile and purgeable priority pollutants in accordance with EPA methods 625 and 624. These tests covered over 110 individual organic compounds. A complete listing of these

Table 5-3. Chlordane Concentrations in Basin Soil Samples

Sampling year	Soil depth, m	Concentration, mg/kg				
		Basin F	Basin G	Basin M	Basin EE	Basin MM
1981	0.00-0.02	1.30	0.22	2.00	0.76	<0.03
	0.02-0.05	0.80	0.16	0.66	1.10	<0.03
	0.05-0.08	0.04	<0.03	0.05	0.74	<0.03
	0.08-0.14	<0.03	<0.03	<0.03	1.20	<0.03
	0.14-0.20	<0.03	0.51	<0.03	<0.03	<0.03
	0.24-0.30	<0.03	<0.03	<0.03	<0.03	<0.03
	0.30-0.60	<0.03	<0.03	<0.03	<0.03	0.04
	0.60-0.90	<0.03	<0.03	<0.03	<0.03	<0.03
	0.90-SZ[a]	<0.03	<0.03	<0.03	<0.03	<0.03
1982	0.00-0.02	1.10	2.70	2.70	0.07	0.63
	0.02-0.05	1.10	2.40	0.27	0.67	0.08
	0.05-0.08	0.11	0.47	0.03	0.63	<0.03
	0.08-0.14	0.07	0.08	<0.03	0.28	<0.03
	0.14-0.20	<0.03	0.04	<0.03	<0.03	<0.03
	0.24-0.30	<0.03	<0.03	<0.03	<0.03	<0.03
	0.30-SZ[a]	<0.03	<0.03	<0.03	<0.03	<0.03
1983	0.00-0.02	1.40	1.50	<0.13	<0.13	<0.13
	0.02-0.05	0.94	1.80	<0.13	<0.13	<0.13
	0.05-0.08	0.14	0.90	<0.13	<0.13	<0.13
	0.08-0.14	0.067	<0.13	<0.13	<0.13	<0.13
	0.14-0.20	0.061	<0.13	<0.13	<0.13	<0.13
	0.24-0.30	<0.03	<0.13	<0.13	<0.13	<0.13
	0.30-SZ[a]	<0.03	<0.13	<0.13	<0.13	<0.13

[a] First "Saturated Zone"

Table 5-4. Lindane, DDT, and DDE Concentrations in Basin Soil Samples

Constituent	Date	Concentration, mg/kg	Basin	Depth, m
Lindane (Gamma BHC)	6-24-81	0.02	F	0.00-0.02
	6-22-81	0.01	F	0.00-0.02
	6-22-81	0.01	F	0.02-0.05
	6-22-81	0.02	F	0.05-0.08
	6-22-81	0.01	F	0.08-0.14
DDT	6-8-82	0.47	G	0.00-0.02
	6-8-82	0.48	G	0.02-0.05
	6-8-82	0.10	G	0.05-0.08
	6-16-82	0.46	M	0.00-0.02
	6-16-82	0.05	M	0.02-0.05
	5-26-82	0.06	EE	0.00-0.02
	5-5-82	0.06	MM	0.00-0.02
DDE	6-10-81	0.04	G	0.00-0.30
	6-8-81	0.03	G	0.02-0.05
	6-8-81	0.03	G	0.14-0.20
	6-8-82	0.05	G	0.00-0.02
	6-8-82	0.06	G	0.02-0.05
	6-8-82	0.02	G	0.05-0.08
	6-17-81	0.02	M	0.00-0.02
	6-16-82	0.04	M	0.00-0.02
	7-31-81	0.01	EE	0.02-0.05
	7-31-81	0.01	EE	0.05-0.08

Note: Concentrations of these three constituents were less than detection limits in all other soil samples.

compounds and their detection limits are included in Appendix B. None of the semivolatile organics were detected in any of the samples. Two of the purgeable organics were detected in one sample (5 to 8 cm depth) in Basin F--toluene at 0.007 mg/kg and methyl cyclohexane at 0.0005 mg/kg. None of the other purgeable organics were detected in any of the samples.

6. Polychlorinated biphenyl (PCB)--PCB was not included in the regular analytical program. However, in the process of running other organics tests, PCB was detected. Thus, several other samples were tested for PCB. Aroclor 1260 was detected in four of eleven samples. Aroclors 1016 through 1262 were not detected. Detection limit for PCB was 0.10 mg/kg. Aroclor 1260 results are listed in Table 5-5.

Table 5-5. Concentrations of Polychlorinated Biphenyl (Aroclor 1260) in soils

	Concentration, mg/kg		
Depth, cm	Basin F	Basin M	Basin MM
0-2	0.18	0.43	ND[a]
2-5	0.22	ND[a]	ND[a]
5-8	0.13	ND[a]	ND[a]
8-14	ND[a]	—	ND[a]

[a] ND = Not detected.

Groundwater

Groundwater data results are divided into three groups: cations and anions, metals, and organics.

Cations and Anions. Soil water and groundwater samples were analyzed for electrical conductivity, cations, and anions to define general mineral quality. These results are summarized in Table 5-6 for samples collected in 1982 and 1983. Soil water samples include all samples collected in the unsaturated zone. There were two or three different sampling depths locations in the unsaturated zone. The groundwater samples were collected at the top of the zone of saturation.

Table 5-6. Concentration of Selected Cations and Anions in Soil Water and Groundwater

Constituent[a]	Location	Basin F			Basin G			Basin M			Basin EE			Basin MM		
		N[b]	Range	Mean	N	Range	Mean	N	Range	Mean	N	Range	Mean	N	Range	Mean
Electrical conductivity	SW[c]	28	54-260	115	2	119-541	330	9	112-294	170	25	46-209	120	13	37-80	52.5
	GW[d]	18	85-377	153	16	595-843	744	12	82-180	109	14	122-246	175	8	37-89	61
Calcium	SW	24	3.7-26.7	9.4	2	8-38	23	8	11-37	18.4	23	3.8-22	11	12	3.0-7.1	4.6
	GW	18	5.9-27	11.1	16	42-64	55	12	5.1-13	8.3	14	8.7-23	15	8	2.8-8	4.5
Magnesium	SW	24	1.0-6.6	3.1	2	3-141	72	8	3.9-7.2	5.5	23	0.45-11	4.2	12	0.76-1.7	1.2
	GW	18	2.5-12	4.7	16	23-45	36	12	2.6-6.3	3.9	14	5.1-12	8.1	8	0.85-3.1	1.9
Sodium	SW	24	2.3-16.6	7.5	2	14.5-70	42	8	5.3-13	8.5	23	2.2-9.2	5.4	12	1.8-4.9	2.6
	GW	18	6.3-17	9.4	16	45-80	55	12	4.9-11	7.2	14	4.7-11	7.4	8	2.4-5.6	3.3
Potassium	SW	24	1.4-4.7	2.4	2	1.2-2.1	1.7	8	2-3.2	2.5	23	1.7-3.8	2.6	12	0.35-1.5	1.1
	GW	18	1.8-4.1	2.4	16	7.4-13	11	12	1.8-3.6	2.4	14	1.7-2.6	2.3	8	1.1-2.4	1.7
Bicarbonate	SW	13	34-131	57	2	34.2-54	44.1	6	84-171	105	20	4-149	67.2	11	16-39	26
	GW	17	37-64	52	13	293-414	356	11	35-104	58	13	64-128	94	7	18-41	29
Sulfate	SW	16	1.6-14.6	5.2	2	5.6-7.2	6.4	6	3.2-14	5.9	20	1-19	4.9	12	0.9-3.3	2.4
	GW	17	2.7-13.8	5.3	14	4-51	36	11	1.3-6.9	4.1	13	1.1-7.1	3.6	7	1.8-4.4	3.1
Chloride	SW	18	1.42-18	6.6	2	1.6-17	9.3	6	0.9-6.1	4.1	20	0.64-10	3.6	12	0.38-5.7	3.6
	GW	17	3.4-53.9	13	16	18-36	28	11	0.89-4.7	2.7	13	1.3-7.3	4.1	7	0.62-4.3	2.7
Nitrate as N	SW	20	0.05-5.9	1.1	2	0.25-0.75	0.50	6	0.12-1.8	1.0	21	0.11-1.8	0.80	11	0.08-0.98	0.26
	GW	17	0.69-13.2	2.8	15	0.83-11	5.6	11	0.11-2.2	0.45	14	0.10-2.6	1.1	7	0.07-1.3	0.44
Phosphate as P	SW	12	0.101-0.20	0.15	2	0.078-0.11	0.094	6	0.173-0.258	0.19	20	0.04-0.202	1.12	9	0.04-0.36	0.15
	GW	13	0.068-0.56	0.174	10	0.026-0.271	0.075	8	0.082-0.40	0.165	11	0.039-0.30	0.126	6	0.02-0.248	0.177

[a] Concentrations are in mg/l, except electrical conductivity which is in umho/cm.
[b] N = Number of samples.
[c] SW = Soil water.
[d] GW = Groundwater.

In comparing the results for the five basins, it is clear that Basin G samples have higher concentrations of most constituents than the other four basins. The area where Basin G is located was previously unsewered and septic tanks and leach pits were used for sewage disposal. This area has been known to have high nitrate concentrations. Table 5-6 indicates that the mean concentration of nitrate in the groundwater samples was 5.6 milligrams per liter (mg/l). Water samples collected beneath Basin MM, the basin with the sandy profile and best permeability, consistently had the lowest mineral concentrations.

Metals. Water samples were regularly analyzed for arsenic and the heavy metals nickel, copper, iron, and lead. Several water samples were tested for the other priority pollutant metals. Detection limits varied because of varying sample size (see Appendix B for detection limits). Results for arsenic, nickel, copper, iron, and lead are summarized in Table 5-7 and described below.

Table 5-7. Range and Median Concentration of Metals in Soil Water and Groundwater

Constituent[a]	Location	Basin F			Basin G			Basin M			Basin EE			Basin MM		
		N[b]	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
Arsenic	SW[c]	22	<1-4	<1	0	—	—	3	<1-5	<1	22	<1-4	<1	10	<1-5	<1
	GW[d]	14	<1-6	<1	15	<1-9	<1	10	<1-8	<1	12	<1-10	<1	6	<1-2	<1
Nickel	SW	22	<1	<1	0	—	—	3	<1	<1	22	<1-11	<1	10	<1-2	<1
	GW	14	<1-1	<1	15	<1	<1	10	<1-1	<1	12	<1	<1	6	<1-1	<1
Copper	SW	16	<1-81	6.4	0	—	—	1	—	42	17	0.1-30	7.9	8	0.5-60	18
	GW	12	<1-16	3.0	12	1.3-75	20	8	0.2-23	2.8	8	0.2-11	2.0	5	2.1-21	3
Iron	SW	16	<1-15	4.0	0	—	—	1	—	<6	17	<1-60	6.5	8	<1-11	3.5
	GW	12	<1-19	3.5	12	<1-21	4	8	<1-9	4.5	8	<1-15	7.0	5	<1-7	1
Lead	SW	16	<1-6	<1	0	—	—	1	—	<2	17	<1-3	<1	8	<1-4	2
	GW	12	<1-1	<1	12	<1-2	<1	8	<1-6	<1	8	<1-2	<1	5	<1	<1

[a] = Concentrations are in ug/l.
[b]N = Number of samples.
[c]SW = Soil water.
[d]GW = Groundwater.

1. Arsenic--Median concentrations of arsenic in both soil water and groundwater were less than detection limits in all basins. The maximum concentration measured was 10 micrograms per liter (ug/l).

2. Nickel--Median concentrations of nickel in both soil water and groundwater were less than detection limits in all basins. Whenever nickel was detected, it was only measured at a concentration of 1 or 2 ug/l.

3. Copper--Copper was detected in most all samples. The highest median concentration in the groundwater was 20 ug/l in Basin G. Median concentrations in the groundwater in the other four basins were 3 ug/l or less.

4. Iron--Iron was also detected in most samples. Highest concentrations were found in Basin EE, while the lowest concentrations were found in Basin MM.

5. Lead--Median concentrations of lead in both soil water and groundwater were less than detection limits in all basins except Basin MM. The median concentration of lead in the soil water in Basin MM was 2 ug/l, only slightly above the detection limit. The lead concentration never exceeded 6 ug/l.

Several water samples were tested for the nine priority pollutant metals not included in the regular testing program. Results are contained in Table 5-8. Antimony, beryllium, cadmium, selenium, silver, and thallium were not detected. Chromium was detected in most samples at a concentration of 0.5 ug/l or less. Mercury was detected in five of eight samples, with the highest concentration being 1.0 ug/l in the groundwater at Basin G. The source of the mercury is unknown, although it was also detected in the runoff samples from all four land use types. Zinc, common to nearly all alluvium, was detected in at least one sample from each basin. The maximum zinc concentration was 90 ug/l in a soil water sample in Basin MM.

Table 5-8. Concentration of Priority Pollutant Metals in Soil Water and Groundwater

	Concentration, ug/l							
	Basin F				Basin G	Basin M	Basin MM	
Constituent	SW1[a]	SW2	SW3	GW[b]	GW	GW	SW2	GW
Antimony	<1	<1	<1	<1	<1	<1	<1	<1
Beryllium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cadmium	<1	<1	<1	<1	<1	<1	<1	<1
Chromium	<0.1	0.5	0.3	0.5	0.3	0.3	0.4	0.1
Mercury	<0.2	0.2	0.2	0.2	1.0	<0.2	<0.2	0.4
Selenium	<1	<1	<1	<1	<1	<1	<1	<1
Silver	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Thallium	<1	<1	<1	<1	<1	<1	<1	<1
Zinc	<10	<10	10	<10	20	20	90	20

[a] SW = Soil water. Samples were collected at one or more locations in the unsaturated zone.

[b] GW = Groundwater. Samples were collected at the top of the water table.

Organics. Water samples were regularly analyzed for chlorinated pesticides, organophosphorus pesticides, chlorophenoxy herbicides, and phenolic compounds. Specific constituents for which analyses were conducted are listed in Appendix B. Two water samples from Basins F and G were also tested for semivolatile organics using EPA Method 625. It was not possible to analyze for the purgeable priority pollutants, since water samples are collected by vacuum. Detection limits for the organics are listed in Appendix B and vary with the size of the available water sample. Results of the testing for organics are described below.

1. Chlorinated pesticides--None of the ten chlorinated pesticides were detected. Detection limits ranged from 0.02 to 1.4 ug/l.

2. Organophosphorus pesticides--Diazinon was the only organophosphorus pesticide detected. It was detected in three soil water samples (once in Basin F and twice in Basin EE) at a concentration of 0.3 ug/l or less. None of the other organophosphorus pesticides were detected. Detection limits ranged from 0.02 to 1.0 ug/l.

3. 2,4,-D--The chlorophenoxy herbicide 2,4-D was not detected in any water sample. The detection limit ranged from 0.25 to 2.2 ug/l.

4. Phenolic compounds--In all samples, total phenols and the specific phenols (pentachlorophenol; 2,4-dinitrophenol; and 4 nitrophenol) were less than the detection limit of 25 ug/l.

5. Semivolatile organics--None of the 59 semivolatile organics covered by EPA Method 625 were detected. Detection limits for most of the constituents were between 10 and 25 ug/l.

Plant Tissue

It was believed that the presence of metals in the surface 30 cm of soil might be reflected in the uptake of these metals by grasses present in the turfed basins. Thus, sets of leaf samples of bermudagrass, dallisgrass, and crabgrass were collected from each of the three turfed basins in 1981, 1982, and 1983. These samples were analyzed for arsenic, nickel, copper, and lead. Mean concentration of these constituents are presented in Table 5-9 for samples collected from the three test basins and nearby control sites.

Although the amount of plant tissue data collected was limited, some general trends are apparent. The data indicated that for bermudagrass and dallisgrass, the range of increase in nickel content was from 0 to 125 percent of that observed in leaves from the control sites. Copper increased from 20 to 90 percent in the turfed basins. Lead showed the greatest increases, which ranged from 110 to 1,300 percent, excluding crabgrass because of only one sample. These results indicate that these plants do take up nickel, copper, and lead that are present in the turfed basins. Statistical tests performed by USDA indicated that the correlation between lead content of grass leaves and lead content of soil is positive but low. Poor correlation is likely due to the fact that the root-density distribution with depth is not the same as for the soil lead distribution with depth, especially for bermudagrass which is deep-rooted. Crabgrass, which is shallow-rooted, could take up more lead, but it grows best near sprinkler heads where excess leaching would be expected.

Table 5-9. Mean Concentration of Metals in Plant Tissue

Sample location	Constituent	Concentration, mg/kg								
		Bermudagrass			Crabgrass			Dallasgrass		
		N	CSS[a]	BSS[b]	N	CSS	BSS	N	CSS	BSS
Basin F	Arsenic	5	<0.1	<0.1	1	<0.1	<0.03	4	<0.2	<0.1
	Nickel	5	2.6	3.5	1	2.9	5.9	4	3.6	8.1
	Copper	5	9.3	11.0	1	13.0	31.0	4	8.8	17.0
	Lead	5	0.31	5.5	1	0.69	14.0	4	1.4	3.0
Basin G	Arsenic	5	<0.2	<0.02	2	<0.3	<0.3	3	<0.2	<0.2
	Nickel	5	4.2	5.4	2	2.5	4.4	3	7.0	6.6
	Copper	5	8.9	13.0	2	7.1	12.0	3	15.0	15.0
	Lead	5	2.1	15.0	2	0.43	1.4	3	1.5	8.0
Basin M	Arsenic	5	<0.1	<0.1	1	<0.1	<0.1	4	<0.1	<0.1
	Nickel	5	2.8	4.6	1	2.1	8.7	4	4.7	6.2
	Copper	5	9.0	13.0	1	15.0	14.0	4	12.0	18.0
	Lead	5	1.3	18.0	1	0.97	6.2	4	1.5	15.0

[a] CSS = Control sampling site.
[b] BSS = Basin sampling site.

ANALYSIS

In this section, the results presented in the previous section are analyzed to determine the effect of various factors on the recharge of stormwater runoff and summer recharge water. The analysis is divided into two main parts: soil profiles and water quality data. In addition, a final section is included that summarizes the mechanisms affecting movement of contaminants in soils.

Soil Profile Comparisons

The following aspects of the soil profile data have been evaluated.

1. Basin samples versus control samples.
2. Effects of storm recharge.
3. Effects of recharge with imported irrigation canal water.
4. Turfed versus unturfed basins and variation with soil type.
5. Spatial distribution of contaminant concentrations.

Basin Samples Versus Control Samples. Comparison of results from basin soil samples and control soil samples is one indicator of the effect of recharge on the soil profile. USDA analyzed the chemical data to determine if the differences between test sites and control sites can be statistically established. By dividing the data into upper soil profile (0 to 3 m) and deeper soil profile (greater than 3 m), it was also possible to evaluate leaching effects. A summary of the USDA statistical analyses is contained in Table 5-10. In this case differences are assumed to be statistically significant if the confidence coefficient is 90 percent or greater.

These statistical results show that runoff water has leached the basin soils to some degree in all five basins. In all basins except Basin G, the electrical conductivity and most of the soluble cations are lower at the test site than in the control. In the deeper soils in Basin F some of the cations are higher in the test basin than in the controls, indicating movement from the surface soils to the deeper soils. The most intensive leaching has occurred in Basin MM, which has a very sandy profile and the greatest permeability.

The concentrations of metals in the basin test site soils have been compared with concentrations in the control test sites. To facilitate the comparison, a background concentration for each metal has been calculated. All of the data collected at the control sites at depths greater then 3 m were used to determine the background concentration, which is assumed to be free of urban runoff pollutants. The median background concentrations of arsenic ranged from 1.7 to 5.9 mg/kg with an overall median of 2.7 mg/kg. Nickel ranged from 5.9 to 25 mg/kg with an overall median of 12.0 mg/kg. Copper ranged from 4.3 to 15 mg/kg with an overall median of 10.0 mg/kg. Lead ranged from 2.0 to 4.9 mg/kg with an overall median of 3.4 mg/kg. A comparison of lead concentration in the test sites with the median background level of 3.4 mg/kg is provided in Table 5-11. Both the maximum and median levels of lead are shown and are expressed as a percentage of the background concentration. In all five basins the median concentrations of lead are greater

Table 5-10. Differences Between Control Soil Sites (CSS) and Basin Soil Sites (BSS) for Selected Chemical Properties

Constituent	Basin F		Basin G		Basin M		Basin EE		Basin MM	
	0-3 m	>3 m	0-3 m	>3 m	0-3 m	>3m	0-3 m	>3 m	0-3 m	>3m
Soluble sodium	-	+		+	-	-	-	-	-	-
Soluble potassium				-		-	-			-
Soluble calcium		+			-	-	-		-	-
Soluble magnesium	-			-	-	-	-		-	-
Exchangeable sodium percentage	+		+							+
Exchangeable potassium percentage	+	+			-	+			+	+
Exchangeable calcium percentage		+	-	+		-			+	+
Exchangeable magenesium percentage	-	-	+			+			-	-
Nitrate nitrogen			+	-		-		-	-	-
Phosphate	-				+		-		-	
Electrical conductivity	-	+			-	-	-	-	-	-
pH				+		-			+	
Soluble chloride		+								
Cation exchange capacity	-	-			-	-		-	- -	- -

Key: m = meters.
+ indicates BSS mean is greater than CSS mean at 90 percent confidence level.
- indicates CSS mean is greater than BSS mean at 90 percent confidence level.
Blank = No statistically significant difference at 90 percent confidence level.

Table 5-11. Soil Lead Concentration with Depth Expressed as a Percentage of Soil Background Concentration

Soil depth, meters	Concentration as percent of background level[a]									
	Basin F		Basin G		Basin M		Basin EE		Basin MM	
	Maximum level	Median level	Maximum level	Median level	Maximum level	Median level	Maximum level	Median level	Maximum level	Median level
0.00-0.02	24,118	19,706	19,188	16,764	47,059	41,176	10,294	9,118	4,118	3,824
0.02-0.05	14,412	10,588	18,529	17,941	12,059	9,412	10,882	7,941	1,059	971
0.05-0.08	2,529	2,382	3,824	6,471	1,706	1,029	5,882	5,000	706	244
0.08-0.14	1,088	912	2,118	1,147	1,235	471	3,235	2,559	253	88
0.14-0.20	599	500	1,147	853	294	232	500	353	94	88
0.24-0.30	824	179	268	238	441	294	112	100	53	38
0.30-0.60	135	126	382	232	382	229	165	141	232	91
0.90-1.20	112	79	215	150	197	106	206	147	65	44
1.50-1.80	88	62	179	115	197	115	353	147	97	26
2.10-2.40	94	91	215	100	138	126	150	59	68	59
2.70-3.00	106	82	262	126	91	71	88	59	59	50

[a] Background concentration of lead is 3.4 mg/kg soil.

than the background level to a depth of about 3 m. Below 3 m, the median concentrations decrease to background levels. The highest lead concentrations were found in Basin M and the lowest were found in Basin MM. Levels of arsenic, nickel, and copper in the surface soils of the test sites (Table 5-2) are also considerably higher than background levels.

Short-Term Effects of Storm Recharge. The short-term effects of storm recharge on basin soils can be demonstrated by looking at concentration profiles before and after the wet weather period. Figure 5-2 shows lead profiles for Basins EE and MM for 1981-82 and 1982-83. Data are plotted from the fall sampling prior to the wet weather period and in the spring after the wet weather period. Both basins had been scraped prior to the fall sample to improve percolation. In Basin EE the spring profile is distinctly higher down to about 0.1 m in 1981-82 and 0.17 m in 1982-83. In Basin MM the increase due to storm recharge is confined to the near surface; below 0.05 m (2 inches) the spring and fall profiles are comparable. In Chapter 6, as part of the loading synthesis, the increases in lead in the soil will be quantitatively compared to runoff loads for that time period.

Another way of estimating the potential effect of recharging storm runoff on the groundwater supply is to compare runoff quality with the regional groundwater quality. Recent groundwater data from 46 municipal supply wells operated by the City of Fresno have been compiled to characterize the regional groundwater quality. These wells are distributed throughout the metropolitan area and provide a reasonable representative of the groundwater quality of the Fresno area. Table 5-12 compares runoff quality at the single-family residential site with the regional groundwater quality.

Table 5-12. Comparison of Runoff and Regional Groundwater Quality

Constituent	Units	Runoff quality at single-family residential site		Regional groundwater quality of 46 wells	
		Mean	Range	Mean	Range
Specific conductance	umhos/cm	56	15-222	308	95-681
pH	Standard units	7.2	6.5-8.3	7.6	7.3-8.1
Alkalinity	mg/l as $CaCO_3$	19	7.0-73	129	40-320
Nitrate	mg/l as N	0.75	0.18-2.1	3.8	1.0-8.4
Calcium	mg/l	5.8	1.3-18	25	6-55
Magnesium	mg/l	1.3	0.01-6.2	14.5	3.5-38
Sodium	mg/l	3.9	0.70-18	21	10-42
Chloride	mg/l	3.4	0.60-14	11.3	2.6-50
Sulfate	mg/l	8.3	4.2-27	8	<1-25
Arsenic	ug/l	1.5	<1.0-8.0	2	<1-4
Cadmium	ug/l	2.0	<1.0-4.0	1	<1-4
Chromium	ug/l	1.4	<1.0-40	3	<1-6
Copper	ug/l	6.1	4.0-180	<50	<50
Lead	ug/l	42	15-2,100	5	<1-8
Mercury	ug/l	0.10	<0.10-8.6	<0.1	<0.1
Zinc	ug/l	70	30-1,300	20	<10-50
Iron	ug/l	188	160-29,000	<20	<20-170
Manganese	ug/l	50	20-480	5	<5-15

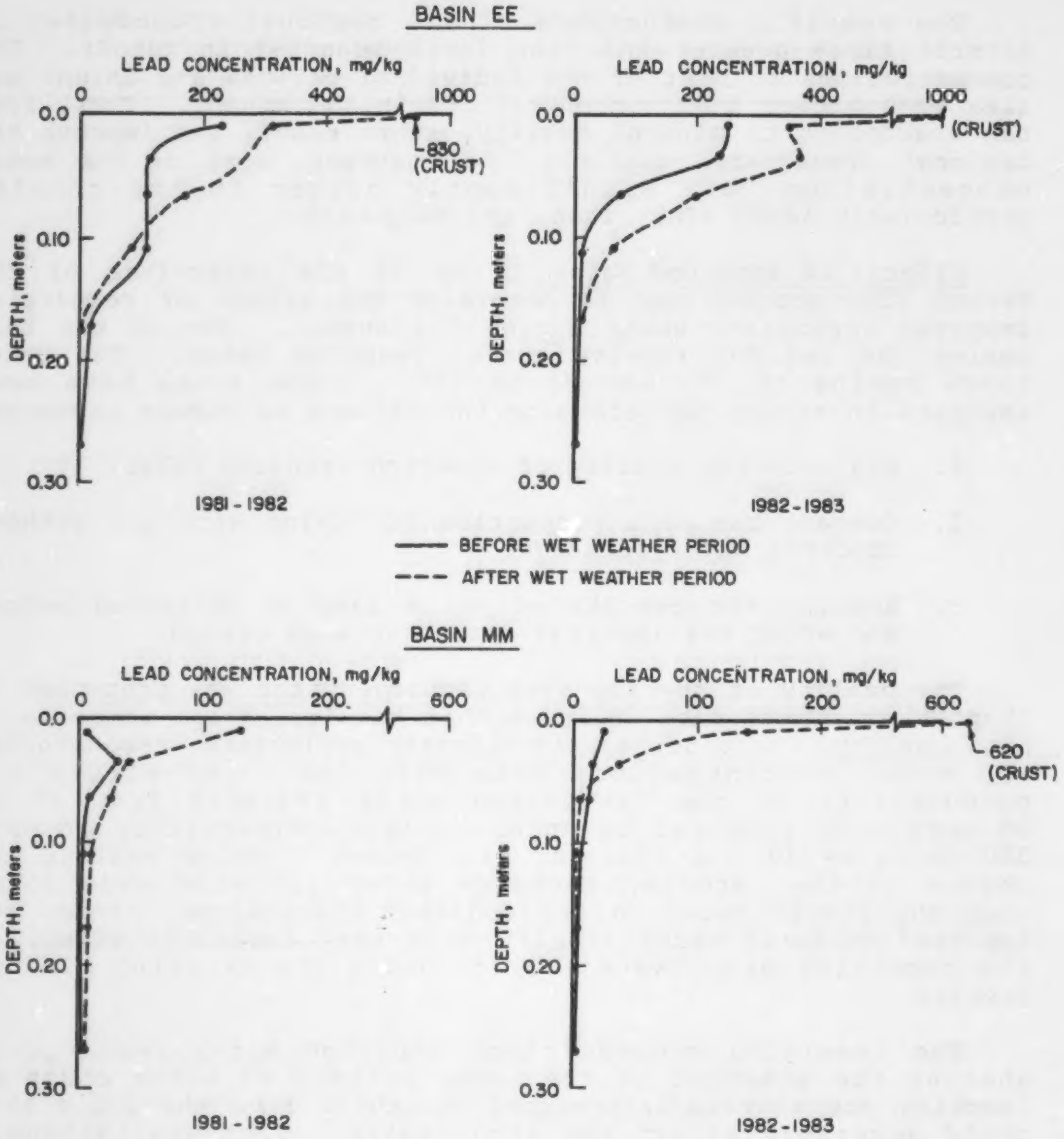


Figure 5-2 Lead Profiles Before and After the Wet Weather Period

The specific conductance of the regional groundwater is several times greater than the level measured in runoff. The concentrations of most of the individual cations and anions are also much higher than concentrations in the runoff. Thus, from the standpoint of mineral quality, storm runoff can improve the regional groundwater quality. In contrast, most of the metal concentrations are significantly higher in the runoff, particularly lead, zinc, iron, and manganese.

Effects of Imported Water. One of the objectives of the Fresno NURP project was to determine the effect of recharging imported irrigation water during the summer. Two of the test basins (EE and MM) receive summer recharge water. The other three basins (F, G, and M) do not. Three areas have been analyzed in trying to determine the effects of summer recharge:

1. Evaluate the quality of imported recharge water.
2. Compare the soil properties of basins with and without imported water recharge.
3. Analyze the results of soils samples collected before and after the imported water recharge period.

The quality of the imported recharge water was presented in Chapter 4. These data indicate that the irrigation water is of high quality. None of organic priority pollutants were detected and metal concentrations were very low. The electrical conductivity of the irrigation water averages from 30 to 35 umhos/cm, compared to an electrical conductivity of over 300 umhos/cm in the regional groundwater. Major cations and anions in the imported recharge water are also much lower than the levels found in the regional groundwater. Thus, the imported recharge water itself has a very favorable effect on the receiving groundwater, by diluting the existing mineral levels.

The remaining concern about imported water recharge is whether the movement of the large volumes of water could be leaching any stormwater-produced compounds from the soils that could adversely affect the groundwater. USDA statistically analyzed the differences in soil chemical properties between the basins with and without imported water recharge. For most of the cations and anions, concentrations tended to be slightly less in the basins receiving imported water recharge, possibly indicating some leaching due to the additional recharge during the summer. However, the magnitude of the differences is generally quite small. Thus, as far as the common cations and anions are considered, imported water recharge is not having a significant adverse impact on the receiving groundwater.

Part of the testing program included collecting soil samples in the spring prior the the imported water recharge period and in the fall after imported water recharge. Prior to collecting the spring samples, 1 to 2 inches of soil was scraped from the basin surface to improve percolation. Lead profiles for Basin EE and Basin MM are presented in Table 5-13 for 1982 and 1983.

Table 5-13. Comparison of Lead Concentrations Before and After Imported Water Recharge

Year	Depth, meters	Lead Concentration, mg/kg			
		Basin EE		Basin MM	
		Before	After	Before	After
1982	0.0-0.3	46.0	55.0[a]	6.2	7.2[a]
	0.3-0.6	2.7	8.8	3.2	7.7
	0.9-1.2	4.1[b]	13.0	1.5[b]	2.1
	1.5-1.8	4.6[b]	3.4	0.9[b]	2.2
	2.1-2.4	2.0[b]	6.3	1.6[b]	1.8
	2.7-3.0	1.5[b]	3.4	1.7[b]	2.4
1983	0.00-0.05	160.0	103.0[a]	16.0	15.0[a]
	0.05-0.08	—	6.5	—	6.6
	0.08-0.14	—	5.3	—	5.6
	0.14-0.20	—	3.1	—	3.2
	0.3-0.6	7.3	—	3.4	—

[a] Computed from individual samples collected over the 0.0 to 0.3-meter depth.

[b] Based on data collected before the basin was scraped.

During 1982, the lead concentration in the upper 0.3 m showed no appreciable increase in either basin. However, in the 0.3 to 0.6 m depth in Basin MM and in both the 0.3 to 0.6 m and 0.9 to 1.2 m depths in Basin EE, lead concentrations were higher after imported water recharge. This indicates that there may be some leaching of lead due to the imported water recharge. Below 1.5 m, lead levels before and after imported water recharge are comparable and are in the range of the background lead concentration found in the control sites which is about 3 mg/kg. During 1983, no soil samples were collected below 0.2 m after imported water recharge, so it is not possible to determine if a similar leaching effect was occurring. Additional data should be collected to confirm whether leaching is occurring.

Turfed Versus Unturfed Basins. Another objective of the project was to determine if there are differences between turfed and untrufed recharge basins. This comparison is complicated by two factors: (1) the two unturfed basins (EE and MM) are the ones that receive summer recharge, while the three unturfed basins (F, G, and M) do not receive summer recharge and (2) the turfed basins are considerably older than the unturfed basins and thus have received a greater accumulation of runoff loads. These two variables make it difficult to focus on just differences due to presence of turfing, but some general comparisons can still be made.

Figure 5-3 shows the median profiles of lead and nickel for all five basins. The turfed basin data are connected with a solid line, while the unturfed basin data are connected with a dashed line.

The surface levels (0.02 m to 0.05 m) of lead are higher in the three older, turfed basins. Of the two unturfed basins, Basin MM with the sandy profile has considerably lower lead concentrations. Since the two unturfed basins are similar in age, this raises the question of whether less of the lead input to Basin MM is being removed in the surface soil layer, as compared to Basin EE. This issue is further evaluated in Chapter 6, when runoff loads are considered. The effect of disking of the surface soils in Basin EE is apparent in the profile; the Basin EE profile is relatively constant between the surface and 0.08 m due to the mixing of the surface soils. In the past, the District has periodically disked surface soils to improve recharge.

The nickel profiles shown on Figure 5-3 also indicate that Basin MM has the lowest concentrations. The nickel profile for the other unturfed basin (Basin EE) is very similar to the profiles for two of the turfed basins (Basins F and G). Disking did not have the effect on the nickel profile as it had on the lead profile.

Two important factors that may be influencing the removal of contaminants in the soil are soil texture and the extent of organic matter. Soils with a higher proportion of silt and clay than sand generally have higher cation exchange capacities and can better attenuate migrating contaminants. Organic matter also adds to the cation exchange capacity of the soil. Table 5-14 shows the levels of silt plus clay and organic matter in the surface soils of the five basins. Basin MM has the lowest levels of silt plus clay and organic matter by a substantial margin. The second unturfed basin (Basin EE) also exhibits a much lower amount of organic matter than the turfed basins. The higher levels of silt plus clay and organic matter in the turfed basins are likely to be contributing to the higher removal of lead and nickel that appears to be occurring on Figure 5-3.

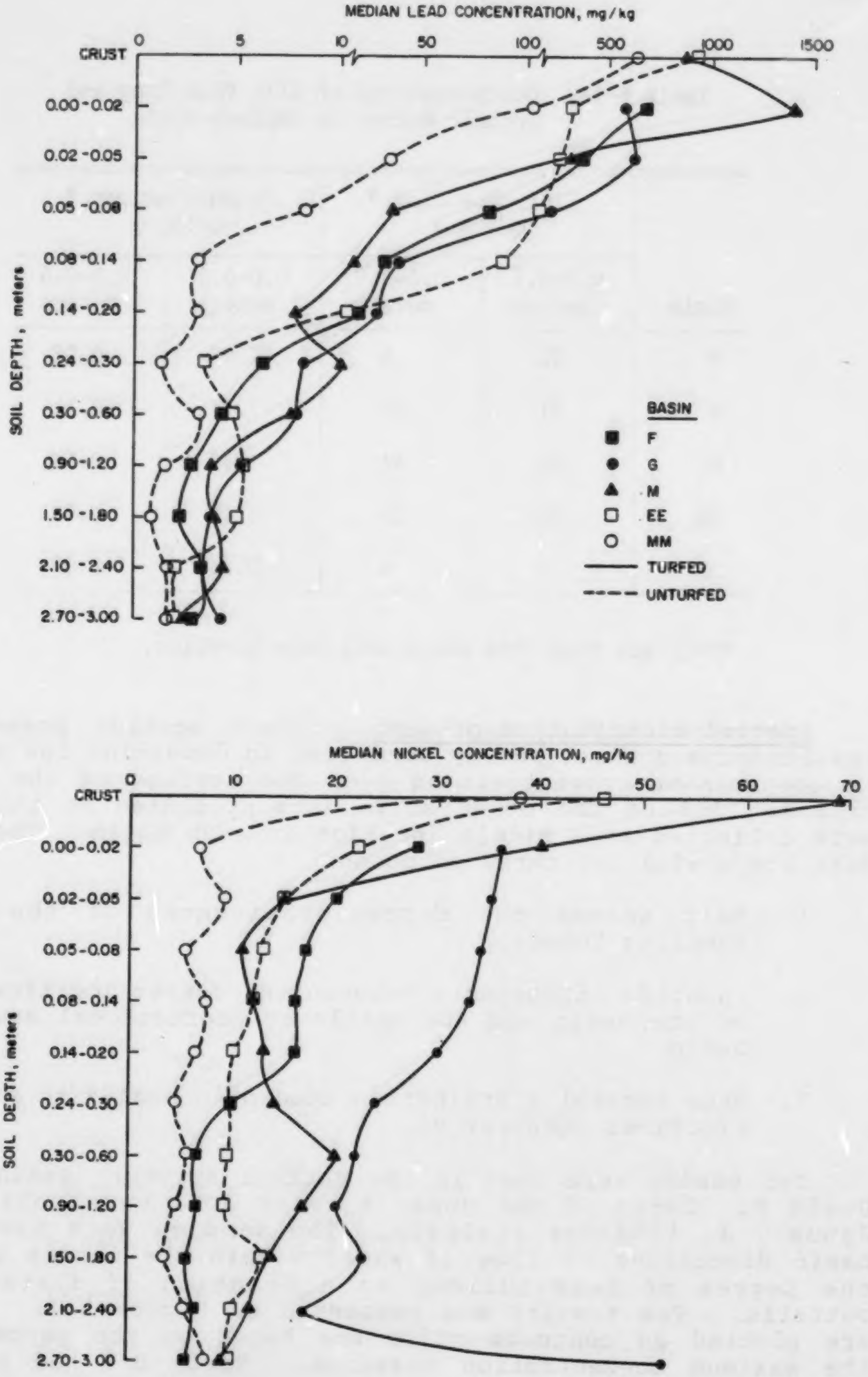


Figure 5-3 Median Lead and Nickel Concentrations in Basin Soils

Table 5-14. Concentrations of Silt Plus Clay and Organic Matter in Surface Soils

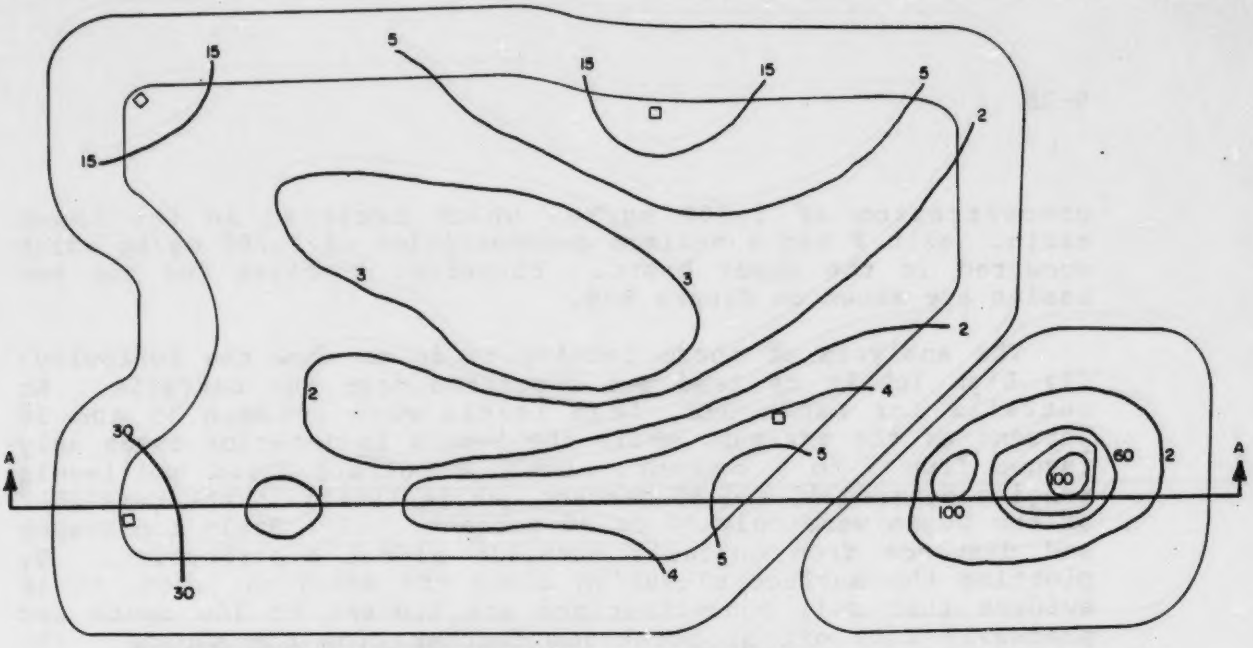
	Silt plus clay,[a] g/100 g		Organic matter,[a] g/100 g	
Basin	0.0-0.3 meters	0.3-0.6 meters	0.0-0.3 meters	0.3-0.6 meters
F	22	5	1.06	0.03
G	31	29	1.14	0.11
M	46	44	1.44	0.16
EE	35	28	0.49	0.01
MM	5	4	0.05	0.03

[a] Data are from 1981 basin soil site profiles.

Spatial Distribution of Lead. This section presents the results of a special survey conducted to determine the variation in contaminant concentrations over the surface of the recharge basins. All of the other soils data presented in this report were collected at a single location in each basin. The spatial data are useful for three purposes:

1. Help assess the representativeness of the regular sampling location.
2. Identify differences between the deeper low-flow portion of the basin and the shallower recreational area of the basin.
3. Show spatial distribution needed in analyzing management practices (Chapter 8).

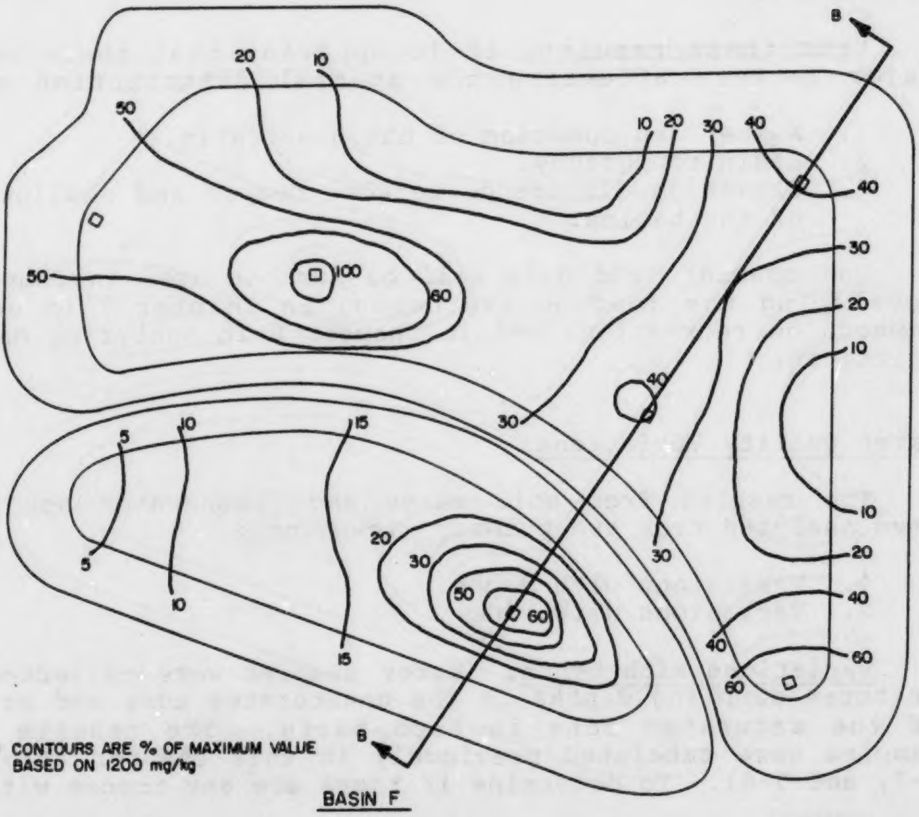
Two basins were used in the spatial survey: Basin B/E and Basin F. Cores of the upper 8 cm of soil were collected on January 3, 1984 for analysis. The samples were taken along basic directions of flow of water within the basins to assess the degree of lead buildup as a function of distance from outfalls. The results are presented on Figure 5-4. The data are plotted as contours which are based on the percentage of the maximum concentration measured. Basin B/E had a maximum



NOTE: CONTOURS ARE % OF MAXIMUM VALUE BASED ON 3300 mg/kg

□ OUTFALLS

BASIN B/E



NOTE: CONTOURS ARE % OF MAXIMUM VALUE BASED ON 1200 mg/kg

BASIN F

□ OUTFALLS

Figure 5-4 Spatial Distribution of Lead in Basin Soils

concentration of 3,300 mg/kg, which occurred in the lower basin. Basin F had a maximum concentration of 1,200 mg/kg which occurred in the upper basin. Elevation profiles for the two basins are shown on Figure 5-5.

The analysis of these results tends to show the following: (1) High levels of lead are deposited near the outfalls. At outfalls for Basin B/E, lead levels were between 15 and 30 percent of the maximum, while the levels in interior areas only ranged from 1 to 5 percent. Basin F outfall areas had levels ranging between 40 and 60 percent, while levels in the remainder of the basin were only 10 to 30 percent. (2) Basin topography and distance from outfalls mutually affect distribution. By plotting the surface elevation along the sampling lines, it is evident that soil concentrations are highest at low spots and gradually fall off at locations farther from the source. (3) The elevation relationship between the shallower recreation area of the basin and the recharge area affects lead buildup in the recreation area. The difference in elevation between B/E basins is roughly 20 feet. The lead levels are about one magnitude higher in the recharge area. At Basin F the difference is only about 2 feet and the lead levels are about the same in the two basins.

From these results, it is apparent that there are three major factors affecting the spatial distribution of lead:

1. Number and location of basin outfalls.
2. Basin topography.
3. Elevation difference between deeper and shallower areas of the basins.

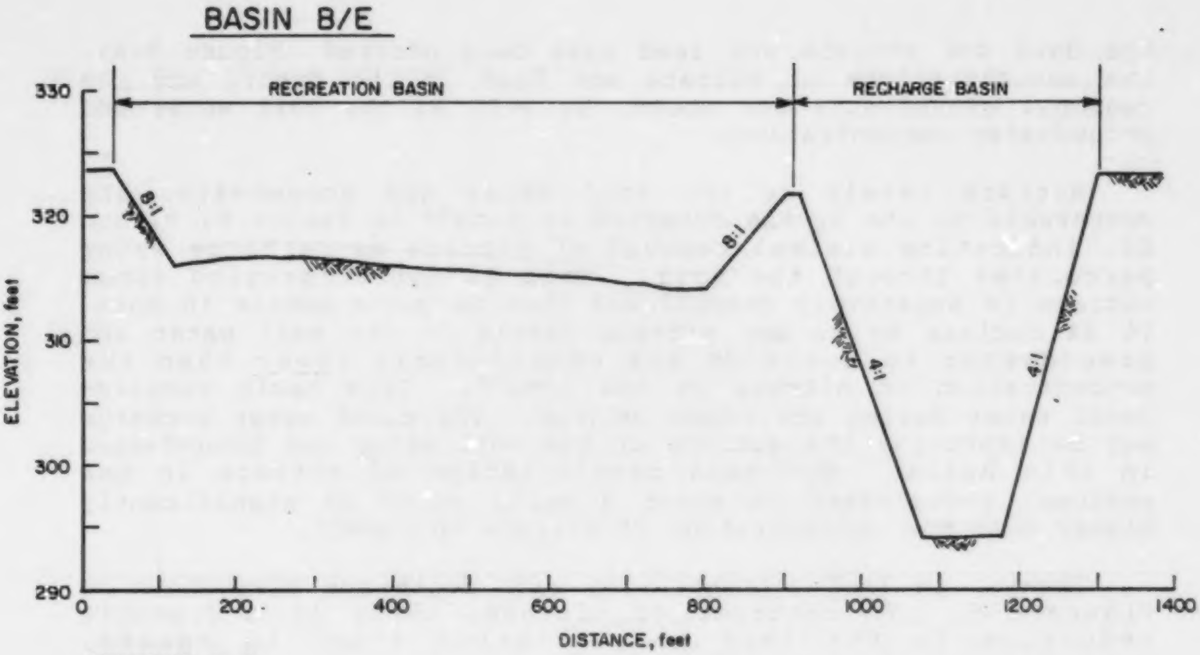
The spatial lead data will be further used in Chapter 6 in developing the loading synthesis; in Chapter 7 in assessing impacts on recreation; and in Chapter 8 in analyzing management practices.

Water Quality Variations

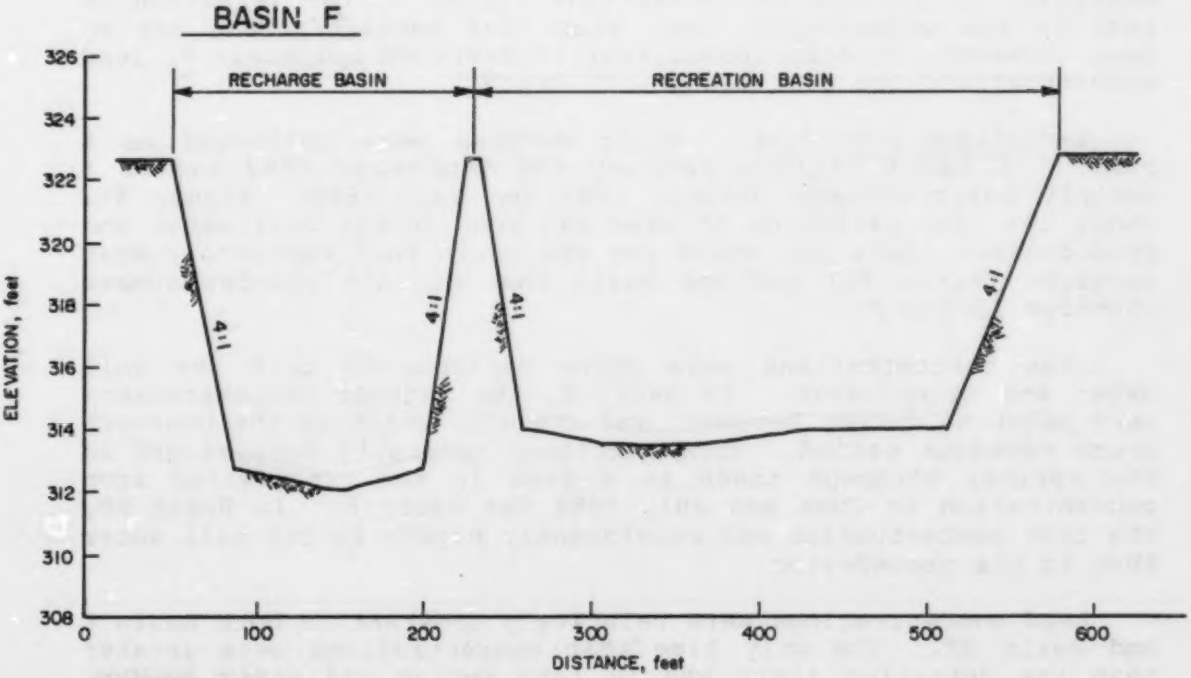
The results from soil water and groundwater samples have been analyzed from two primary viewpoints:

1. Variations with depth.
2. Variations with time.

Variations with Depth. Water samples were collected at two or three sampling depths in the unsaturated zone and at the top of the saturated zone in each basin. The results for the samples were tabulated previously in this chapter (Tables 5-6, 5-7, and 5-8). To determine if there are any trends with depth,



SECTION A-A



SECTION B-B

Figure 5-5 Basin Elevation Profiles

the data for nitrate and lead have been plotted (Figure 5-6). The concentrations of nitrate and lead in the runoff and the regional groundwater are shown, as well as the soil water and groundwater concentrations.

Nitrate levels in the soil water and groundwater are comparable to the levels detected in runoff in Basins F, M, and EE, indicating minimal removal of nitrate as recharge water percolates through the soil. This is not surprising since nitrate is negatively charged and thus is quite mobile in soil. It is unclear as to why nitrate levels in the soil water and groundwater in Basin MM are considerably lower than the concentration of nitrate in the runoff. This basin receives canal water during the summer months. The canal water recharge may be improving the quality of the soil water and groundwater in this basin. The mean concentration of nitrate in the regional groundwater is about 4 mg/l, which is significantly higher than the concentration of nitrate in runoff.

Changes in lead concentration with depth are also shown on Figure 5-6. In contrast to nitrate, there is a dramatic reduction in the lead concentration found in runoff. Concentrations in the soil water and groundwater range between less than 1 ug/l and 8 ug/l compared to median level of 150 ug/l in the runoff. It is also important to note that the levels of lead in the soil water and groundwater are generally lower than the concentration of lead in the regional groundwater. It is difficult to discern any consistent trends in the variation of lead in the unsaturated zone, since the concentrations are so low. However, it does appear that in Basin MM and Basin F, lead concentrations are decreasing with depth.

Variations with Time. Water samples were collected on a bimonthly basis between January and September 1982 and on a monthly basis between October 1982 and July 1983. Figure 5-7 shows the time variation of lead and iron in the soil water and groundwater. Data are shown for one basin that received summer recharge (Basin EE) and one basin that did not receive summer recharge (Basin F).

Iron concentrations were quite variable in both the soil water and groundwater. In Basin F, the highest concentrations were measured during December and January, which is the heaviest storm recharge period. Concentrations generally dropped off in the spring, although there is a rise in the groundwater iron concentration in June and July 1984 for Basin F. In Basin EE, the iron concentration was consistently higher in the soil water than in the groundwater.

Lead concentrations were relatively constant in both Basin F and Basin EE. The only time that concentrations were greater than the detection limit was in late spring and early summer, after the winter recharge period.

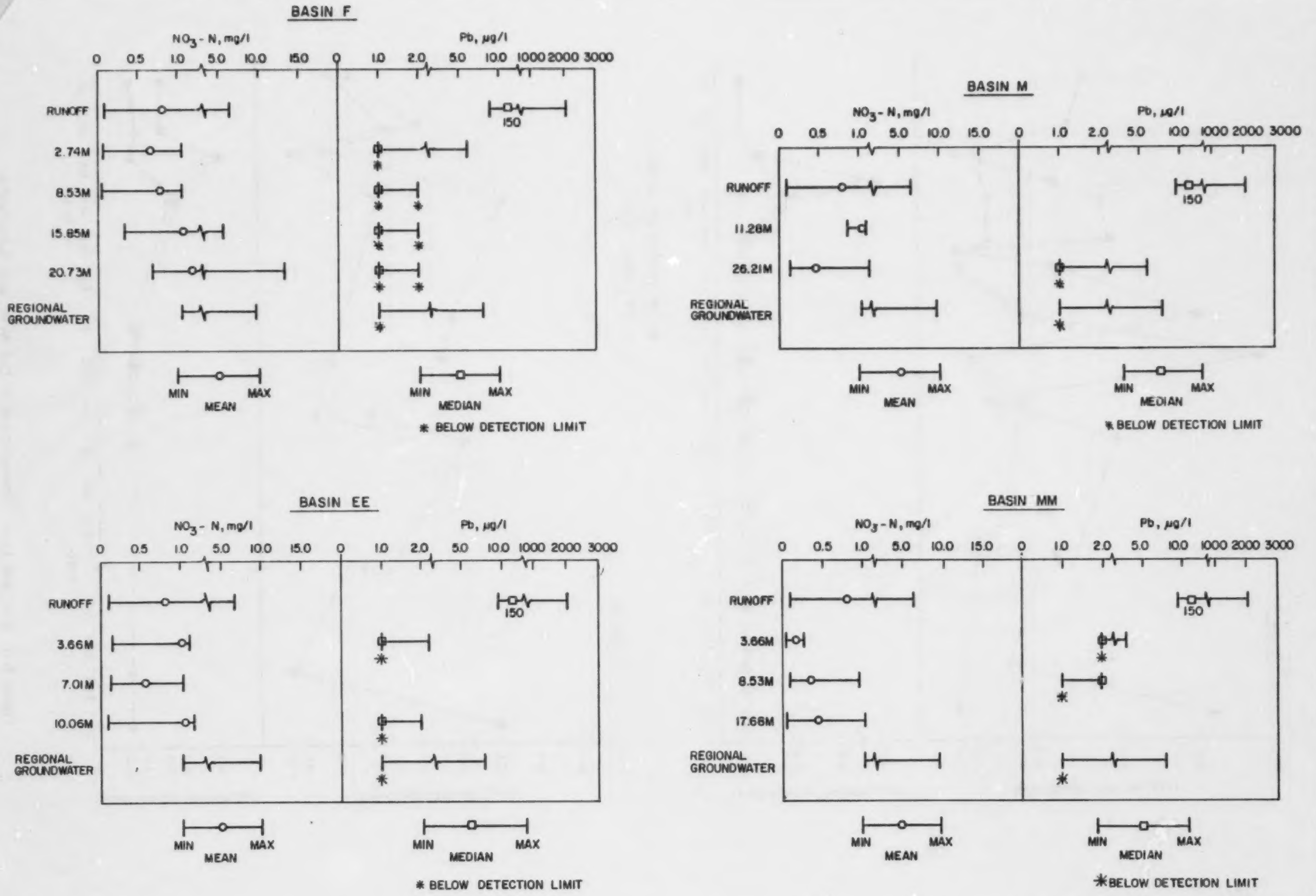


Figure 5-6 Variances in Water Quality with Depth

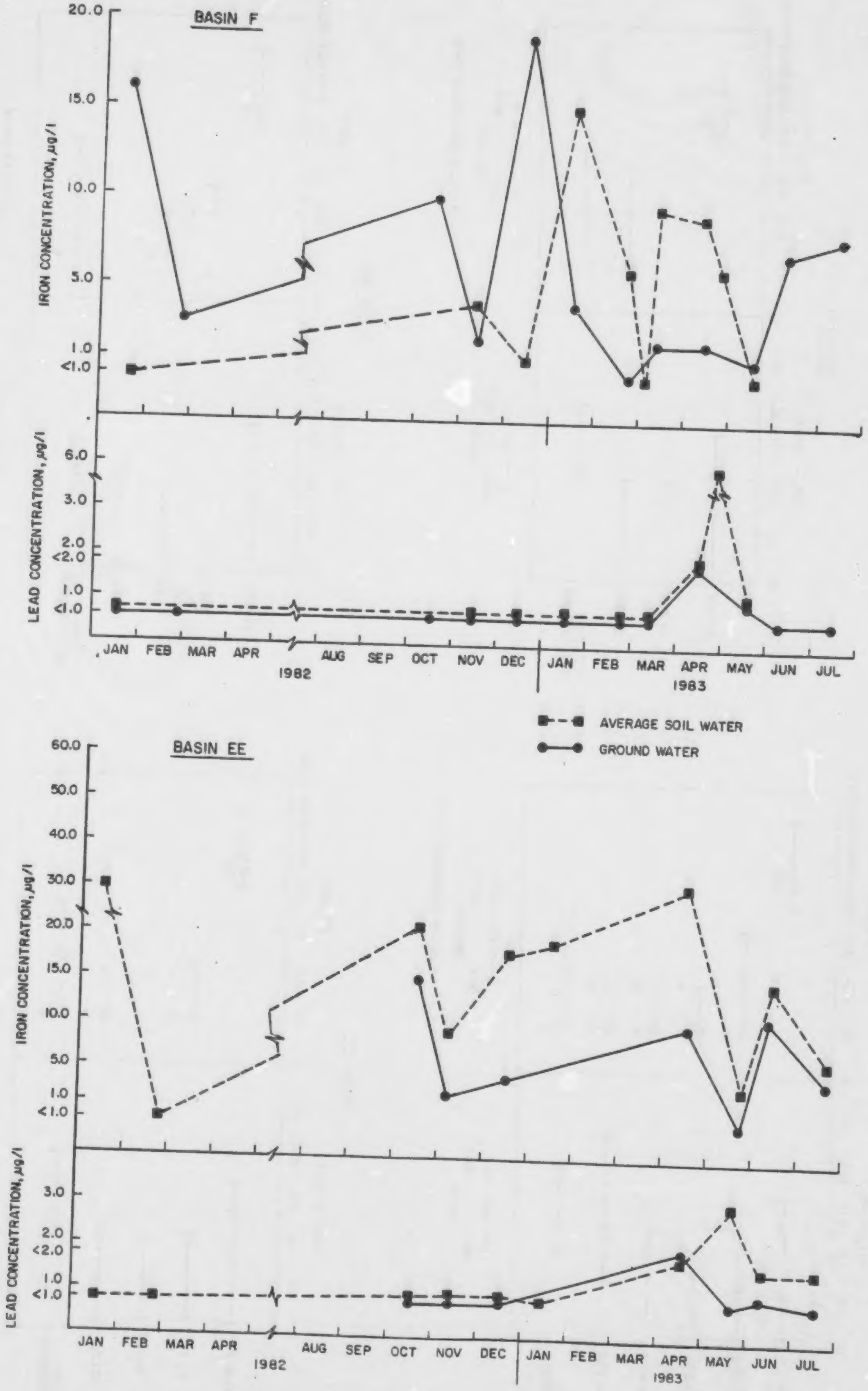


Figure 5-7 Iron and Lead Concentrations in Soil Water and Groundwater

Contaminant Migration in Soils

The data and analyses presented in this chapter have dealt specifically with the soils and groundwater monitoring program conducted in Fresno. The following discussion provides a general explanation of the mechanisms affecting movement of contaminants in soils. This discussion is intended to help further explain the significance of the Fresno data previously presented and to provide some background for the discussions of impacts and management practices in Chapters 7 and 8. The discussion focuses primarily on metals.

The migration of contaminants through the soil has been studied by numerous people over the years. The soil has been referred to as the living filter because of its ability to retain, modify, or decompose a wide variety of organic and inorganic contaminants. Relatively little investigative work has been done directly on groundwater recharge of urban runoff, but extensive work has been done on renovation of municipal sludges and effluents. This research in most cases is applicable to the question of contaminant migration in the soils underlying urban runoff retention basins.

Land Disposal of Wastewater Effluents. Land treatment and disposal of wastewater effluents has been successfully practiced for many years. Unfortunately, limited metals data are available in many cases, since metals in treated municipal effluents are often present in very low concentrations which are less than the detection limits of normal metal analyses. Table 5-15 presents selected metal data from the Central Treatment Plant in Sacramento, California. Although this effluent is not used for irrigation of crops, it is of a suitable quality. Table 5-15 also presents comparable data on Sacramento River water. The metals level in the Central Plant effluent, Sacramento River water, and runoff samples collected as a part of the NURP study are at comparable levels for arsenic and copper. Lead is significantly higher in the Fresno runoff, while nickel is somewhat higher in the effluent. The Sacramento River is used directly for irrigation throughout the Central Valley and provides natural recharge for groundwater aquifers.

Metals occur in runoff and wastewaters in the soluble and insoluble form. Insoluble material is in the form of precipitates or is attached to colloidal material in the wastewater. In aquatic systems, the soluble form of the metal often has the greatest toxic effect on aquatic organisms. The insoluble form is relatively less toxic, presumably due to reduced availability, unless it is converted to the soluble form. However, when the runoff percolates in the soil, the difference between the soluble and insoluble forms become much less significant. Once the runoff becomes a part of the soil solution, the soluble and insoluble metals participate in a wide variety of physical, chemical, and biochemical reactions. These reactions are discussed in more detail in the following sections.

Table 5-15. Comparison of Runoff to Municipal Effluent and River Water

Source	Constituent			
	Arsenic	Copper	Lead	Nickel
Fresno urban runoff average of residential and commercial land use	2	18	150	13
Secondary treated municipal effluent,[a] Sacramento, California	19	22	8	90
Sacramento River[a]	<10	5	<2	35

[a] "Toxicant Monitoring Program," Sacramento Regional Wastewater Management Plan, Sacramento Area Consultants, March 1980.

Factors Affecting Contaminant Migration. Urban runoff temporarily stored or disposed of in the runoff retention basins contains a wide variety of organic and inorganic contaminants. Some of the contaminants are at levels that could be harmful if it were possible for them to directly enter the groundwater. As discussed previously most of the contaminants are removed from the water by the near surface soils resulting in a relatively clean leachate that will ultimately reach the groundwater. The metals that have been regularly monitored in the soil are arsenic, copper, lead, and nickel. This section discusses the various organic and inorganic processes responsible for removing these contaminants from the runoff.

Numerous physical, chemical, and biochemical processes influence the mobility of these elements in the soil. These proccesses in turn are based on certain characteristics of the soil. The following key soil characteristics and their effect on contaminant migration are described in this section.

1. Soil texture
2. Cation exchange capacity
3. pH
4. Oxygen
5. Organic matter

Physical factors include soil texture and particle size and soil pore space distribution. Soil texture, which is the relative quantity of sand, silt, and clay, combined with the amount of pore space, has a major influence on the rate of water movement through the soil. Reducing the rate of water movement allows other time-dependent processes to remove these elements from the runoff. In some instances the soil actually filters out larger particulate contaminants such as asbestos or large precipitates of ionic elements, such as iron and manganese.

Cation exchange capacity (CEC) has been identified as having a major influence on soil contaminant migration. CEC refers to the negative charge that exists on most soil particles which then attract and temporarily retain positively charged ions in the soil solution. Most of the metals of concern in this study, including copper, lead, and nickel are positively charged. Arsenic is the only element studied which is found most often in a negatively charged form. Soils with high CEC tend to be more effective at removing positively charged contaminants from leachates. The ion exchange reactions that occur between positively charged ions and negatively charged soil particles play an important part in delaying migration, but usually do not inhibit the ion from eventually being leached downward. In a soil with a high CEC, numerous processes will attenuate the migration of ions. As a contaminant moves through the soil, it will participate in other physical, chemical, and biochemical processes that will more permanently inhibit its migration. The significance of these processes in a soil tends to increase in proportion to the CEC and surface area of a soil. Thus, soils with high CEC such as silty and clayey soils provide greater opportunities for attenuation of migrating contaminants.

Hydrogen ion activity (pH) has been shown to have a significant effect on ion migration. In a well buffered calcareous soil (containing calcium carbonate), most heavy metals and arsenic will form relatively insoluble precipitates which are resistent to leaching. In acid soils or in poorly buffered soils which may become acidified due to leaching, these precipitates will not form, or previously precipitated ions may be dissolved thus making contaminants available for leaching. The effect of pH changes is most pronounced in sandy soils which have little or no calcareous materials and are thus easily acidified by leaching or addition of acidifying materials such as some nitrogenous fertilizers or organic wastes that upon decomposition release organic acids. The effects of calcareous soil materials on the mobility of various contaminants varies from one heavy metal to another. In general though, a soil with a pH of 7 or greater is more effective in controlling metal migration than the same soil with a low pH. The Central Valley Regional Water Quality Control Board requires that soils used for disposal of reclaimed wastewater and sludges be maintained at a pH of 6.5 or greater. Many soils will naturally maintain this level; if not, limestone materials can be added to maintain the pH at 6.5 or above.

The pH levels for soils in the retention basins are generally at pH 7 or above, except for some of the profiles for Basins F, EE, and MM. None of the basin soil samples contained free lime. The soils are non-calcareous. Basin EE shows the most dramatic reduction in soil pH between the 1981 and fall 1982 sampling data. The pH values dropped from near neutral to less than pH 5. The pH in the sandy surface soil of Basin MM with its low buffering capacity also dropped during the same period. Both of these basins received irrigation canal water for recharge during the summer of 1982. The pH in Basin F was only less than 7 in the near surface soil. The lowered pH in these basins could be the result of chemical additions possible from fertilizer. The pH of the runoff from the residential and commercial areas is above pH 7. This water would not tend to lower the soil pH. The pH in the runoff from the industrial areas is sometimes less than pH 7. If this low pH water were consistently drained into one basin, it could over a period of years, lower the pH of the surface soils. Periodic monitoring will determine if this is occurring.

The amount of oxygen in a soil affects the migration of metals. The microorganisms in the soil have a major impact on the mobility of metals. The organisms exist in a complex food chain whereby organic matter is converted into other organic compounds with the releasing of mineral elements into the soil. The amount of oxygen in the soil influences the type of organisms that will thrive and the biochemical reactions that will occur.

Aerobic or oxidizing conditions favor attenuation of contaminants, while anaerobic or reducing conditions favor accelerated migration of contaminants. Water logging of soils, as would occur temporarily under the retention basins, would tend to favor contaminant migration if the oxygen content decreases. However, if the basins are drained in between storms, the frequent wetting and drying that occurs would favor attenuation. It also temporarily favors an increase in the permeability of the surface soil layer.

Organic matter in the soil has a generally decelerating influence on trace contaminant mobility. Soil organic matter, like silt and clay particles, increases the cation exchange capacity of the soil and favors the mechanisms which retain metals. Through biochemical processes involving soil organic matter and soil microorganisms, organic colloids are formed which will retain many metals and result in the formation of insoluble precipitates. The presence of organic chelators (humic and fuluic acids) can promote the formation of chelated metals. Chelated metals are bound into organic complexes, which are mobile in certain soil conditions such as alkaline or very permeable soils. This is not expected to be a problem in neutral soils such as those found in the Fresno basins which were tested.

As discussed above, there are a wide range of processes that affect contaminant mobility. The relative mobility of 13 metals is listed in Table 5-16. This table presents the relative mobilities under aerobic or nonwaterlogged conditions. Under anaerobic conditions, the mobility of most of these ions would be increased. Those tending to form the most insoluble precipitates such as cadmium would still be the least mobile under anaerobic conditions.

Organic Pesticides. The soils data showed little or no migration of the organochlorine or organophosphorus pesticides below the top 24 cm of soil. Many of the mechanisms that retain metals in the soil also retain or cause the retention of pesticides. In addition, many of the pesticides are oxidized or decomposed by soil bacteria.

Chlordane was detected up to the 24 cm depth and lindane, DDT, and DDE were detected, down to a depth of 5 cm. These three pesticides are relatively immobile in the soil and will probably not migrate any deeper. Soil adsorption is probably the most important process affecting the migration of all pesticides and, in particular the organochlorine pesticides. Adsorption occurs as a result of contact of the pesticide with clay or organic substances in the soil. The relative lack of mobility suggests that the organochlorine pesticides may be so tightly adsorbed that they do not participate in exchange reactions. This is unlike the metallic ions which may be adsorbed onto the clay but still be available for exchange reactions, especially if there is a change in solution equilibrium as a pH change.

The organophoshorus pesticides were not detected in any of the soils. This is probably due to their relative short life in the soil. Organophosphorous pesticides are typically decomposed in the soil in less than 12 weeks.

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Table 5-16. Relative Mobility of Selected Elements in Soil

Mobility class	Element	Comments
Relatively mobile	Cyanide	Not strongly retained by the soil.
	Selenium	Not strongly retained by the soil, at normal pH levels.
Moderately mobile	Iron Zinc Nickel Lead Copper	Absorbed more strongly by the soil in the order of $Cu^{++}>Pb^{++}>Ni^{++}>Zn^{++}>Fe^{++}$. Stability for complexes of any given type should be increasing in the order of Fe>Zn>Ni>Pb>Cu.
	Beryllium	(Chemistry in soils probably similar to aluminum.)
Slowly mobile	Arsenic	Mobility similar to phosphorus.
	Cadmium	Forms insoluble precipitates in oxidizing conditions.
	Chromium	Forms insoluble precipitates in oxidizing conditions.
	Mercury	Retained in the surface layer of most aerated soils.
	Asbestos (< 2um)	Particles less than 2um, are retained in surface layer of soils like clay.
Immobile	Asbestos (> 2um)	Particles >2um, or greater than clay size are retained on the surface of soils.

CHAPTER 6

SYSTEM ANALYSIS

The Fresno Nationwide Urban Runoff Program (NURP) project consisted of two main data collection programs. Extensive data were collected by the U.S. Geological Survey (USGS) on the concentrations and loads of pollutants in urban runoff. These data are discussed in Chapter 4. Chapter 5 contains a discussion of the soils and groundwater data collected by the U.S. Department of Agriculture (USDA). In this chapter, the data are integrated and pollutants are traced through the entire system from rainfall to regional groundwater.

SYSTEM COMPONENTS

There are seven major system components that were studied in the Fresno NURP project: rainfall, dry deposition, street particulate material, runoff, basin soils, soil water, and groundwater. Table 6-1 shows which metals and organics were detected in each component. As shown in the table, not every constituent was analyzed in every component. Copper, lead, nickel, and iron were detected in all components of the system. Arsenic was detected in every component except rainfall and mercury was detected in every component except street particulates. Although not analyzed in every component, chromium, zinc, aluminum, and manganese were detected in every component in which they were analyzed. Many organics were not analyzed in all system components. A number of organics were detected in runoff, but not in soils, soil water, or groundwater. Lindane, chlordane, DDE, and DDT were found in soils, but not in soil water or groundwater.

The system components are shown on Figure 6-1. Pollutants in dry deposition accumulate on the ground surface until a rainstorm occurs. Pollutants in rainfall, the accumulated dry deposition pollutants, and pollutants from other sources that have accumulated on street surfaces are transported to the storm drainage system. These pollutants are then measured in the storm runoff. The storm runoff is transported via the drainage system to the recharge basins. The recharge water percolates through the basin soils, eventually reaching the shallow and then the deep groundwater.

The ranges and mean values of lead, specific conductance, calcium, and nitrate in each of the system components are shown in Table 6-2 to demonstrate changes that occur in the

Table 6-1. Metals and Organics Detected in Fresno NURP Project

Constituent	Component						
	Rainfall	Dry deposition	Street particulates	Runoff	Basin soils	Soil water	Groundwater
Priority pollutant metals							
Antimony	-	-	-	X	-	O	O
Arsenic	O	X	X	X	X	X	X
Beryllium	X	-	-	-	-	O	O
Cadmium	-	-	X	X	-	O	O
Chromium	X	X	X	X	-	X	X
Copper	X	X	X	X	X	X	X
Cyanide	-	-	-	X	-	-	-
Lead	X	X	X	X	X	X	X
Mercury	X	X	O	X	X	X	X
Nickel	X	X	X	X	X	X	X
Zinc	X	X	X	X	-	X	X
Other metals							
Aluminum	X	X	X	X	-	-	-
Barium	X	-	-	X	-	-	-
Boron	-	-	-	X	-	-	-
Cobalt	-	-	-	X	-	-	-
Iron	X	X	X	X	X	X	X
Lithium	X	-	-	X	-	-	-
Manganese	X	X	X	X	-	-	-
Molybdenum	-	-	-	X	-	-	-
Strontium	X	-	-	X	-	-	-
Titanium	-	-	-	X	-	-	-
Vanadium	-	-	-	X	-	-	-
Priority pollutant organics							
Aldrin	O	O	O	X	O	O	O
Anthracene	-	-	-	X	O	O	O
Benzo(a) pyrene	-	-	-	X	O	O	O
Benzo(b) fluoranthene	-	-	-	X	O	O	O
α-BHC	-	-	-	X	-	-	-
γ-BHC (lindane)	X	X	X	X	X	O	O
Butyl benzyl phthalate	-	-	-	X	O	O	O
Chlordane	X	X	X	X	X	O	O
Chrysene	-	-	-	X	O	O	O
DDD	O	O	X	O	O	O	O
DDE	X	X	X	X	X	O	O
DDT	X	O	X	X	-	-	-
Dieldrin	X	O	X	X	-	-	-
Di-n-octyl phthalate	-	-	-	X	O	O	O
Endosulfan	X	O	X	X	O	O	O
Endrin	O	O	O	X	-	-	-
Fluoranthene	-	-	-	X	O	O	O
Heptachlor	O	O	X	X	-	-	-
Heptachlor epoxide	O	O	X	X	-	-	-
4-nitrophenol	-	-	-	X	O	O	O
Total PCB	X	O	X	X	X	-	-
Pentachlorophenol	-	-	-	X	O	O	O
Phenol	X	-	-	X	X	O	X
Pyrene	-	-	-	X	O	O	O
Other organics							
Diazinon	X	X	X	X	O	X	O
Dibromochloropropane	-	-	-	X	-	-	-
2,4-D	X	O	O	X	O	O	O
Ethion	X	O	O	O	O	-	-
Malathion	X	X	X	X	O	O	O
Methoxychlor	X	X	O	X	O	O	O
Methyl parathion	X	O	X	X	O	O	O
Parathion	X	O	X	X	O	O	O
Silvex	O	O	-	X	-	-	-
Trithion	O	O	X	X	-	-	-

[a]Table symbols: X indicates detected; O indicates not detected; - indicates not measured.

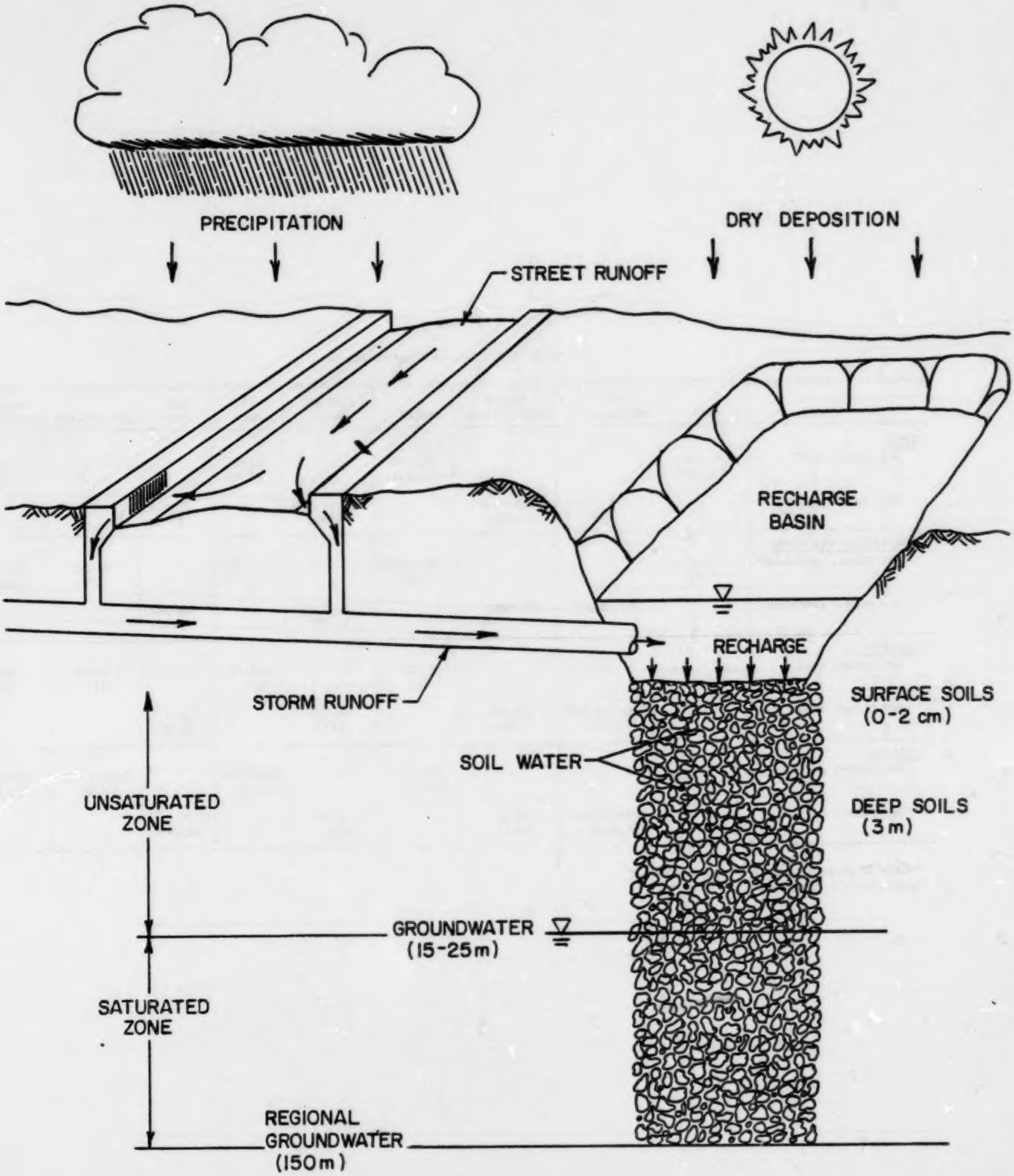

Figure 6-1 Schematic of System Components

Table 6-2. System Concentrations

Constituent	Rainfall	Dry deposition	Street particulates	Runoff	Surface soil	Soil water	Deep soil	Groundwater	Regional groundwater
Lead									
Wet phase, ug/l	<1-61 (11.2)[a]			9-2,100 (204)		<1-6 (1.5)		<1-6 (1.3)	<1-8 (5)
Dry phase, mg/kg		140-8,280 (1,464)	100-1,000 (500)		8.7-1,600 (585)		<2-8.9 (2.9)		
Specific conductance									
Wet phase, umhos/cm[b]	3-57 (14)			8-9,960 (199)		37-541 (118)		37-843 (278)	131-443 (308)
Dry phase, umhos/cm		No data	No data		1,519-4,031 (2,239)		78-204 (114)		
Calcium									
Wet phase, mg/l	0.1-1.5 (0.5)			0.8-120 (11)		3.0-38 (11)		2.8-64 (21)	6-55 (25)
Dry phase, mg/kg		2,760-121,000 (18,113)	30-120 (59)		54-299 (183)		1.2-3.5 (2.0)		
Nitrate									
Wet phase, mg/l	0-0.96 (0.23)			0-6.6 (0.9)		0.05-5.9 (0.8)		0.07-13.2 (2.4)	1.0-8.3 (3.8)
Dry phase, mg/kg		1,200-295,000 (24,455)	<2-42 (8.7)		1.9-101 (52)		0.18-1.1 (0.68)		

[a] Numbers in parentheses are mean values.

[b] umhos/cm = Micromhos per centimeter.

runoff/recharge system for different types of constituents. The data from each land use type and each recharge basin have been grouped together to show the overall ranges and mean values. Concentrations for the regional groundwater quality are also contained in Table 6-2, based on the data presented previously in Table 5-12.

The lead concentrations were fairly low in rainfall [mean = 11.2 micrograms per liter (ug/l)] and quite high in runoff (mean = 204 ug/l), indicating that lead comes primarily from ground sources. The concentrations decreased to about 1.5 ug/l in soil and groundwater. The mean lead concentration in the regional groundwater is higher than the mean levels in the soil water and groundwater underlying the recharge basins. In the dry phase, the highest lead concentrations were found in dry deposition [mean = 1,464 milligrams per kilogram (mg/kg)]. The mean concentrations of 585 mg/kg in surface soil and 2.9 mg/kg in deep soil indicate that the lead generally is attenuated in the surface soil layer and does not migrate to the deep layers of soil. The lead in the runoff is reduced to background levels by the time the runoff water reaches the water table.

The specific conductance and concentrations of calcium and nitrate in both the wet and dry phases show similar patterns. In the wet phase, the concentrations are low in rainfall, somewhat higher in runoff and soil water, even higher in the groundwater, and highest in the regional groundwater. For example, the mean concentrations of calcium were 0.5 mg/l in rainfall, 11 mg/l in runoff and soil water, 21 mg/l in groundwater, and 25 mg/l in the regional groundwater. In the dry phase, the concentrations were highest in dry deposition, lower in street sweepings, slightly higher in surface soil, and lowest in deep soil. The mean calcium concentrations were 18,113 mg/kg in dry deposition, 59 mg/kg in street sweepings, 183 mg/kg in surface soil, and 2 mg/kg in deep soil. The high concentrations of these constituents in dry deposition combined with the concentrations in rainfall and street particulates result in the high runoff concentrations.

The soil water concentrations of calcium and nitrate were essentially equal to the runoff concentrations, indicating that the soil layer has minimal effect on these particular constituents. However, it is also important to note that the concentrations of calcium and nitrate in the runoff are lower than in the regional groundwater. Thus, as discussed in Chapter 5, the runoff water being recharged is tending to improve the quality of the regional groundwater for calcium and nitrate, as well as most of the other cations and anions.

LOADING ANALYSIS

The effects of urban runoff on the recharge basin soils can be further assessed by performing a loading analysis. The purpose of the loading analysis is to determine if the pollutant loads from runoff and other sources can be correlated with the amounts of these pollutants present in the basin soils. The USDA soil profile data can be used to compute the amount of various pollutants in the basin soils. The runoff monitoring program was conducted on a different set of basins, so actual runoff loads for the USDA basins are not available. However, runoff loads to the USDA basins can be "synthesized" using the unit load factors for different land use types from the USGS data. The loading analysis was developed for both a short-term period (i.e., the two years of this study program) and a long-term period.

Short-Term Analysis

Basins EE and MM were chosen for the short-term loading analysis because data on pollutant concentrations in the soil were collected before and after the wet weather season in 1981-82 and 1982-83. Thus, it is possible to calculate a mass balance for each year. Samples were not collected in the fall for the other three test basins. The results of the short-term loading analysis are described below.

Runoff Load. The loads of lead, copper, iron, and arsenic in runoff from the drainage areas of Basins EE and MM were synthesized using the USGS runoff data. USGS collected runoff quality data from single-family residential, multiple-family residential, commercial, and industrial land uses. Unit runoff load factors in pounds per acre per year were calculated for each land use type in the 1981-82 and 1982-83 rain seasons. The unit runoff load factors were based on flow-weighted runoff coefficients and flow-weighted event mean concentrations (EMCs). The unit runoff load factors were multiplied by the number of acres of land in each land use type in the drainage areas of Basins EE and MM to calculate the annual runoff load for each of the two years.

A small amount of runoff water is pumped out of Basins EE and MM each year to prevent flooding. It was estimated that 5 percent of the water was pumped out of Basin EE and 1 percent of the water was pumped out of Basin MM. Typically, the pumps are turned on as soon as the basins begin to fill with runoff water, so it was assumed that there was minimal sedimentation of particulates in the runoff water prior to pumping. Based on this assumption, the runoff loads to Basins EE and MM were reduced by 5 percent and 1 percent, respectively, to account for the pollutant loads that are pumped out of the basins and never reach the basin soils.

Rainfall and Dry Deposition Loads. There is rainfall and dry deposition directly on the basins. The loads of lead, copper, iron, and arsenic in this direct rainfall and dry deposition were calculated. USGS measured the concentrations of these constituents in rainfall and dry deposition at the single-family residential and industrial sites. Based on these concentration data, unit load factors in pounds per acre per year were calculated for both sites. The mean unit load factors for rainfall and for dry deposition were multiplied by the surface areas of Basins EE and MM to determine the pollutant loads from direct rainfall and dry deposition. The runoff and rainfall-dry deposition loads are shown in Table 6-3. The loads of each constituent in rainfall and dry deposition are negligible in comparison to the runoff loads.

Table 6-3. Runoff, Rainfall, and Dry Deposition
Loads to Basins EE and MM

	Annual loads, pounds					
	Basin EE			Basin MM		
Constituent	Runoff	Rainfall and dry deposition	Total	Runoff	Rainfall and dry deposition	Total
Lead						
81-82	183	1	184	75	1	76
82-83	648	2	650	251	1	252
Copper						
81-82	30	1	31	10	1	11
82-83	46	1	47	17	1	18
Iron						
81-82	4,503	47	4,550	1,945	29	1,974
82-83	20,238	37	20,275	9,182	22	9,204
Arsenic						
81-82	5	0	5	1	0	1
82-83	8	0	8	3	0	3

Soil Loads. USDA measured the concentrations of lead, copper, iron, and arsenic at 2-to-6-centimeter (cm) depth intervals in the soil column. The soil content or load of each of these constituents in the upper 14 cm of the soil column was calculated at the following times:

Fall 1981--soil load at beginning of study.

Spring 1982--soil load after 1981-82 rain season.

Fall 1982--soil load before 1982-83 rain season.

Spring 1983--soil load after 1982-83 rain season.

If there was no loss of pollutants from the basin soils, the spring 1982 soil loads in Basins EE and MM would equal the fall 1981 soil loads, plus the loads from runoff, rainfall, and dry deposition occurring during the 1981-82 wet weather season. Similarly, the spring 1983 soil loads would equal the fall 1982 soil loads, plus the loads from runoff, rainfall, and dry deposition occurring during the 1982-83 wet weather season. The loads are compared in Table 6-4. In most cases, the calculated loads are within 30 percent of the measured soil loads. The exceptions are lead in Basin MM in both years, copper in Basin EE in 1981-82 and in Basin MM in both years, and arsenic in Basin EE in 1982-83. In four of these cases, the actual load measured in the basin was less than the calculated load. This would imply that all of the load contributed by runoff does not remain in the basin soils. In Basin MM the actual loads of lead and copper were greater than the calculated loads in 1981-82. This implies that the runoff load was overestimated or the soil load was underestimated. There are no consistent differences between the results in Basins EE and MM. For example, in some cases, Basin MM soil loads accounted for less of the runoff load than Basin EE (1982-83 lead and copper). The opposite was true for the 1981-82 lead and copper data and the 1982-83 arsenic data, with Basin MM soil loads accounting for more of the runoff load than Basin EE.

Factors Affecting Short-Term Loading Analysis. There are a number of factors which affect the results of the loading analysis that were not included in the calculations. It was not possible to quantify them and include them in the analysis, but they can be qualitatively considered and are briefly described below.

1. Estimates of amount of runoff water pumped out of the basins--There are no measurements of the amount of water pumped out of the two basins. The figures of 5 percent and 1 percent are simply estimates. If more volume was pumped out than these estimates, the runoff load would be overestimated. In addition, it was assumed that all of the pollutants in the pumped runoff water were pumped out of the basins and that there was no settling of particulate pollutants in the basins. This assumption would tend to underestimate the load to the basins.

Table 6-4. Comparison of Actual and Calculated Soil Loads

Time	Constituent load, pounds							
	Lead		Copper		Iron		Arsenic	
	Basin EE	Basin MM	Basin EE	Basin MM	Basin EE	Basin MM	Basin EE	Basin MM
1981-82								
Fall soil load	1,409	78	218	24	141,000	46,100	72	18
Runoff load[a]	184	76	31	11	4,500	2,000	5	1
Calculated spring soil load	1,593	154	249	35	145,500	48,100	77	19
Actual spring soil load	1,925	253	111	56	111,000	35,700	63	16
Actual load as percent of calculated load	121	164	45	160	76	74	82	84
1982-83								
Fall soil load	1,434	106	152	41	159,000	50,100	185	39
Runoff load[a]	650	252	47	18	20,200	9,200	8	3
Calculated spring soil load	2,084	358	199	59	179,200	39,500	193	42
Actual spring soil load	2,586	245	177	39	No data	No data	41	39
Actual load as percent of calculated load	124	68	89	66	—	—	21	93

[a] Runoff load is actually the load from runoff, rainfall, and dry deposition.

2. Representativeness of USDA sampling sites--USDA sampled at one site in Basins EE and MM. Spatial sampling was not conducted in these two basins to determine if the sampling sites were generally representative of the basins. Spatial data collected in Basin F showed that highest concentrations were found near the inlets and in low spots on the basin floor. Based on this information, the sampling sites in Basins EE and MM appear to be fairly representative of average conditions.

3. Basin floor surface area--The surface area used to calculate the amount of each pollutant in the basin soil was based on an estimate of the average water depth in the basins during the rain seasons. District staff estimate that the average water depth was as follows: Basin EE, 10-feet in 1981-82 and 15 feet in 1982-83; and Basin MM, 8-feet in 1981-82 and 12-feet in 1982-83. The basin floors are not entirely flat, so there are low areas that fill with water more often. The depth of water in the basins varies with the duration and intensity of each rainstorm.

Long-Term Analysis

A long-term mass balance of lead, copper, iron, and arsenic in Basin F was calculated. Basin F was chosen because data were available on the development of the watershed during the 19 years since the basin was constructed and USDA conducted an intensive survey of lead concentrations throughout the basin. From the intensive survey, the representativeness of the study sampling site could be determined.

Runoff Load. The loads of lead, copper, iron, and arsenic in runoff from the drainage area of Basin F were calculated for the period from 1965, when the basin was constructed, to 1983. The acres of land in each land use type in 1965, 1970, 1975, and 1981 were determined. These figures were multiplied by the flow-weighted unit runoff load factors to produce annual loads. The unit runoff load factors from 1982-83 were used for 1969 and 1978 because the rainfall amounts in these two years were significantly above normal, as was the rainfall in 1983. The unit load factors from 1981-82 were used for all of the other years between 1969 and 1983. The annual loads from 1969 to 1983 were summed to produce the accumulated runoff load. The accumulated loads are presented in Table 6-5.

Table 6-5. Accumulated Runoff Loads to Basin F

Constituent	Accumulated runoff load, pounds			
	Before pumping	After pumping	Recharge basin	Recreation basin
Lead	720	576	167	409
Iron	15,081	12,065	3,499	8,566
Copper	85	68	20	48
Arsenic	13.1	10.5	3.0	7.5

Approximately 20 percent of the runoff water is pumped out of Basin F each year to prevent flooding. Since the pump is turned on as soon as the basin begins to fill with water, it was assumed that there was no settling out of particulates, so 20 percent of the pollutant load is pumped out of the basin. The accumulated loads of each pollutant were reduced by 20 percent to account for the pollutant loads that are pumped out of the basin and never reach the basin soils. These adjusted loads are also shown in Table 6-5.

Basin F consists of two basins; a small (1.16-acre) recharge basin and a larger (2.82-acre) recreation basin. The runoff water enters the recharge basin and then overflows to the recreation basin. Since there are no data on the amount of water stored in each basin during a typical year, it was assumed that the amount of water and pollutant loads were directly proportional to the surface areas of the two basins. Based on this assumption, 29 percent of the accumulated load was distributed in the recharge basin and 71 percent was distributed in the recreation basin. These loads are shown in Table 6-5.

Rainfall and Dry Deposition Loads. The loads of lead, copper, iron, and arsenic in the rainfall and dry deposition falling directly on the surface of Basin F are included in the background soil load which is discussed in the following section. These loads were less than 5 percent of the runoff load.

Soil Loads. The loads of lead, copper, iron, and arsenic in the soil of Basin F were calculated by using the average concentration of each constituent in each layer of soil measured by USDA during the study. The soil background concentrations of lead, copper, iron, and arsenic were subtracted from the soil concentrations before the soil load was calculated. The background concentrations were based on data collected at the control site in 1981. These soil loads are presented in Table 6-6.

Table 6-6. Soil Loads in Basin F

Constituent	Soil load based on long-term sampling site, pounds		Soil load based on average data, pounds	
	Recharge basin	Recreation basin	Recharge basin	Recreation basin
Lead	329	799	194	751
Iron	120,992	294,136	71,385	276,488
Copper	1.9	4.5	1.1	4.2
Arsenic	4.7	11.4	2.8	10.7

In January 1984, USDA conducted an intensive sampling program in Basin F to determine the spatial variability in the basin. These data are useful in determining if the long-term sampling site is representative of average conditions in the basin. In the recharge basin, the average lead concentration in the upper 8 cm of soil was 204 mg/kg. The average concentration in the upper 8 cm of soil at the long-term sampling site during the study period was 344 mg/kg. Thus, the average concentration in the recharge basin during the intensive survey was 59 percent of the average at the long-term sampling site. The average concentration in the recreation basin during the intensive survey was 322 mg/kg, which is 94 percent of the average long-term sampling site. Since intensive data were not collected on the concentrations of copper, iron, and arsenic, it was assumed that the long-term sampling data overestimated the average concentrations by the same percentages. The soil loads, based on data collected at the long-term sampling site, were multiplied by 59 percent for the recharge basin and 94 percent for the recreation basin to obtain estimates of the average soil loads. These loads are also presented in Table 6-6.

If there were no loss of pollutants from the basin soils, the soil load of each constituent should approximately equal the load from runoff since the basin was constructed. Table 6-7 presents the soil loads as a percent of the accumulated runoff load. The soil loads presented are based on the adjustment to reflect average conditions. The lead and arsenic soil loads based on the average data are fairly close to the accumulated runoff loads. The recharge basin loads are slightly lower than the loads from runoff and the recreation basin loads are higher. This indicates that proportioning the runoff load between the two basins based on surface areas, may have underestimated the load to the recharge basin and overestimated the load to the recreation basin. If the two basins are combined, the soil loads of lead and arsenic are 164 and 129 percent of the runoff load, respectively. The soil loads of iron were much greater than the runoff loads and the soil loads of copper were much lower than the runoff loads.

Table 6-7. Comparison of Soil Loads to Runoff Loads

Constituent	Soil load as percent of runoff load based on average data	
	Recharge basin	Recreation basin
Lead	116	184
Iron	2,040	3,228
Copper	6	9
Arsenic	93	143

Factors Affecting Long-Term Loading Analysis. As in the case of the short-term analysis, there are several factors that influence the long-term loading analysis that cannot be quantified. However, these factors can be qualitatively considered and are described below.

1. Estimate of amount of runoff water pumped out of the basin--As described in the short-term analysis, this assumption could either underestimate or overestimate the runoff load.

2. Estimate of surface area of basin routinely covered with water--As described in the short-term analysis, there is no clear basis for judging the effect of this assumption on the loading analysis.

3. Applicability of study period data to previous years--The data collected during 1981-82 and 1982-83 were used to estimate loads from 1965 through 1983. Differences in land use over the 19-year period were accounted for in the synthesis, as discussed previously. Differences in rainfall amounts were only partially incorporated into the synthesis. The annual rainfall for each year

since 1965 was obtained. The unit load factors, in pounds per acre per year, from 1981-82 were used for years in which the rainfall was less than 17 inches. The unit load runoff factors from 1982-83 were used for years in which the rainfall exceeded 17 inches. The unit load factors may vary with changes in rainfall, but it was not possible to predict the relationship between rainfall amount and runoff factors with only two years of data.

4. Changes in cultural practices--Since the analysis of Basin F extends over a 19-year period, it is likely that there have been cultural changes during this time that may influence unit runoff loads. The best example is the effect of the reduction in leaded gasoline use. The use of leaded gasoline has changed dramatically since the basin was completed in 1965. Figure 6-2 shows the amount of leaded gasoline consumed in Fresno County since 1960 and projections for future consumption. The consumption of leaded gasoline increased steadily from 1960 to 1973. It has decreased steadily since then, due mainly to the introduction of unleaded gasoline cars in 1975. Chevron Oil Company has projected that it will continue to decrease in the future. The runoff lead load was based on data collected from 1981 to 1983, a period when leaded gasoline usage was lower than in any of the years since 1965 when Basin F was completed. Historic runoff loads of lead were likely much higher than the current loads used in our analysis. Thus, the cumulative lead runoff load is significantly underestimated.

   Changes in street sweeping practices could also influence the magnitude of runoff loads. For example, there was a significant reduction in street sweeping after the passage of Proposition 13 in 1978.

Summary of Loading Analysis

Both the short-term and long-term loading analyses are influenced by several important variables that could not be quantified. Thus, the comparison of runoff loads with soil loads does not represent a complete mass balance. However, some general insights can still be obtained from the evaluation.

In the short-term loading analysis, the loads present in the basin soils were comparable to the runoff loads in the majority of cases. However, there were four cases in which the actual load measured in the basin was substantially less than the incoming runoff load. Three of the four cases occurred in

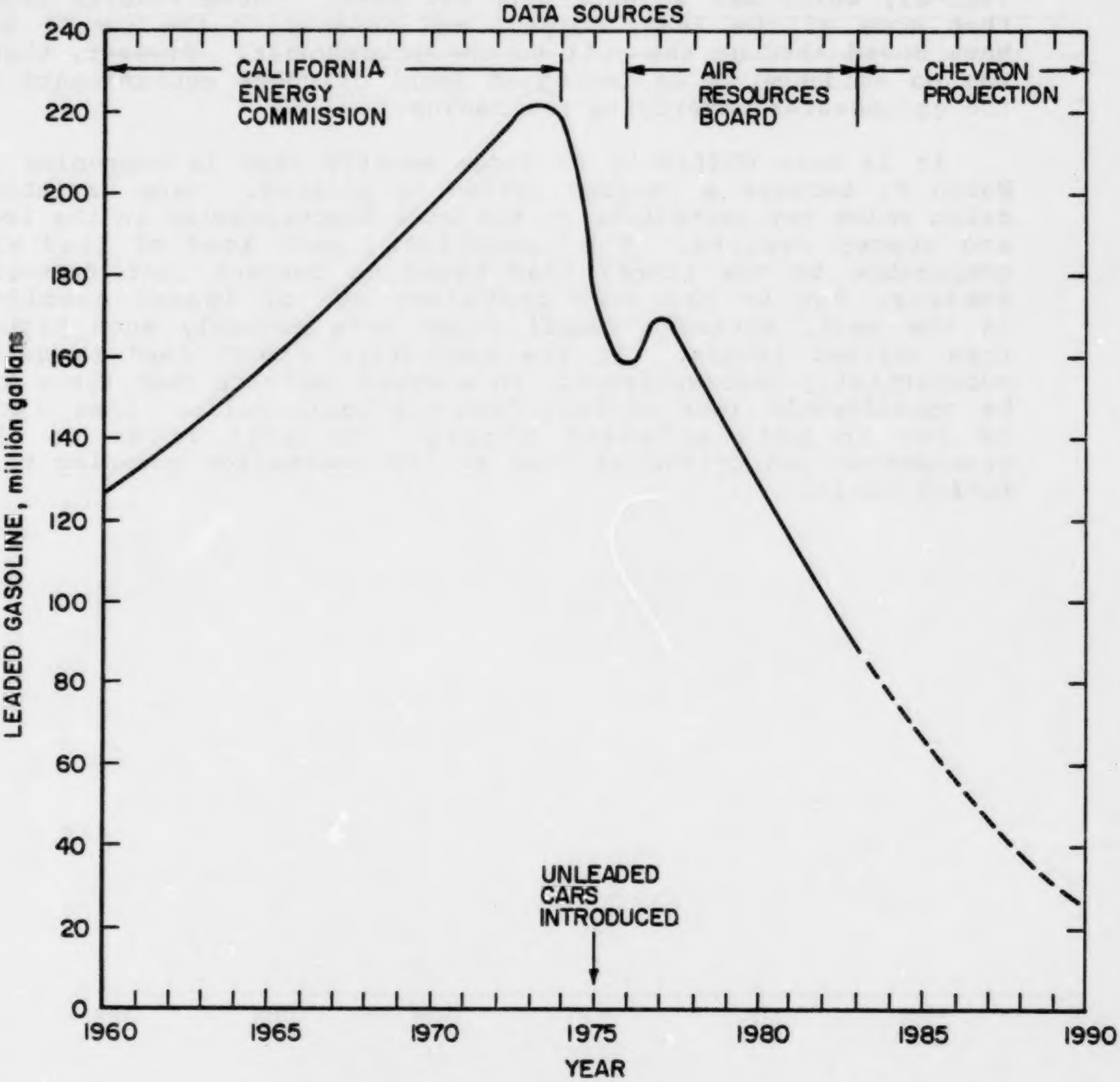

Figure 6-2 Leaded Gasoline Consumption in Frenso County, 1960-1990

1982-83, which was an extremely wet year. These results imply that some of the lead, copper, and arsenic in the runoff may have moved through the soil to the groundwater. However, there was no evidence of an increased level of these contaminants in the groundwater underlying the basins.

It is more difficult to judge exactly what is happening in Basin F, because a 19-year period is covered. Many variables exist which may contribute to the wide discrepancies in the iron and copper results. The accumulated soil load of lead was comparable to the runoff load based on current unit factors. However, due to the more prevalent use of leaded gasoline in the past, historic runoff loads were probably much higher than current levels. If the cumulative runoff load is being substantially underestimated, this would indicate that there may be considerable loss of lead from the basin soils. Loss could be due to both movement through the soil layer to the groundwater and uptake of lead by the vegetation covering this turfed basin.

CHAPTER 7

IMPACTS OF RUNOFF ON WATER SUPPLY AND RECREATION

The effects of the retention of urban storm runoff in recharge basins on groundwater and soils in the Fresno area are discussed in this chapter. The runoff data from the four land use types, rainfall data, and the soil water and groundwater data are compared to the Safe Drinking Water Act (SDWA) criteria and drinking water criteria developed by the California Department of Health Services (DHS) and the Environmental Protection Agency (EPA). The concentrations of several metals and organics in the soil samples are compared to soil criteria for hazardous materials developed by DHS. These comparisons are one method of determining if recharge of urban runoff is adversely affecting groundwater quality underlying the basins and surface soils in the basins used for recreational purposes.

DRINKING WATER IMPACTS

The effects of the retention of urban storm runoff in recharge basins on the quality of the drinking water supply are discussed in this section. The runoff, rainfall, soil water, and groundwater data are compared to drinking water criteria.

Drinking Water Criteria

There are a number of state and federal criteria for metals and organics. The data collected during this program have been compared to the drinking water quality criteria or maximum contaminant levels pursuant to the SDWA. These SDWA criteria are generally similar to the criteria used by the State of California in evaluating water supplies. The data are also compared to DHS Action Levels and EPA Suggested No Adverse Response Levels (SNARLs). These Action Levels and SNARLs are not legally enforceable criteria, but are simply DHS and EPA recommendations on safe levels for drinking water supplies.

Runoff Data. Comparing the quality of urban runoff to the drinking water criteria is not a direct indicator of water supply impacts. The concentrations of most contaminants found in storm runoff will be reduced as the runoff water percolates through the soil layer. Most municipal and industrial water supplies are extracted from depths of up to 400 feet below ground surface. Thus, comparing runoff quality to drinking water criteria represents a "worst case" and is intended primarily to determine what constituents in urban runoff are of potential concern to the groundwater supply.

Table 7-1 presents the SDWA criteria, DHS Action Levels, and EPA SNARLs for parameters that were measured by the U.S. Geological Survey (USGS) or EPA. The maximum and median concentrations of the metals and organics at the industrial site are compared to the criteria in this table. The data from the single-family residential, multiple-family residential, and commercial sites were combined and the maximum and median concentrations were determined. Since the EPA priority pollutant program consisted of only four organics samples and six metals samples at each site, the more comprehensive USGS data are compared to the criteria. In the few cases where parameters were not measured by USGS, the EPA data are presented.

The metals can be divided into several groups:

1. Maximum and median concentrations lower than SDWA criteria: cadmium, copper, zinc, and silver at the industrial site; arsenic, copper, zinc, and silver at the other sites. Since the detection limit for selenium in testing done by the EPA contract laboratories (25 ug/l) exceeds the criterion (10 ug/l), it is not possible to determine if selenium meets the criterion.
2. Median concentration lower than SDWA criterion, but maximum concentration exceeds criterion: arsenic, chromium, and mercury at the industrial site; cadmium, chromium, and mercury at the other sites.
3. Maximum and median concentrations exceed the SDWA criteria: lead, iron, and manganese at the industrial and other sites.

Most of the metals exceed the SDWA criteria by a small amount; however, iron, manganese, and lead significantly exceed the criteria. The criteria for iron and manganese are based on taste and odor concerns, while the criterion for lead is based on health effects. The EPA is currently in the process of reviewing the SDWA criteria. They are considering revising the cadmium and lead criteria downward. The maximum concentration of cadmium at the residential and commercial sites exceeds the current criterion. The maximum and median lead concentrations at all sites exceed the current criterion. When the cadmium and lead criteria are revised, they should be compared to lead and cadmium groundwater concentrations to reassess the potential impact of these metals on the drinking water supply.

Table 7-1. Comparison of Runoff Quality with Drinking Water Criteria and Action Levels

Constituent	Data source	Criterion ug/l	Industrial site concentration, ug/l			Other sites concentration, ug/l		
			N[a]	Maximum	Median	N[a]	Maximum	Median
SDWA constituents[b]								
Arsenic	USGS	50	107	67	14	246	17	2
Cadmium	USGS	10	70	4	1	133	12	1
Chromium	USGS	50	86	51	14	186	62	10
Copper	USGS	1,000	86	400	66	185	380	18
Lead	USGS	50	107	360	74	249	2,100	140
Mercury	USGS	2	107	2.5	0.1	247	8.6	0.1
Zinc	USGS	5,000	86	3,100	535	185	3,400	150
Iron	USGS	300	107	62,000	9,000	250	72,000	2,900
Manganese	USGS	50	37	1,600	360	116	1,700	190
Selenium	EPA	10	6	<25	<25	18	<25	<25
Silver	EPA	50	6	<10	<0.5	18	<10	<0.5
Lindane	USGS	4	19	0.27	0.03	67	0.06	0.01
Endrin	USGS	0.2	19	0.01	<0.01	67	0.01	<0.01
Methoxychlor	USGS	100	19	0.04	<0.01	67	0.19	<0.01
Silvex	USGS	10	19	0.07	<0.01	65	0.03	<0.01
Toxaphene	USGS	5	19	1.0	<0.01	67	1.0	<1.0
2,4-D	USGS	100	19	3.2	0.03	65	3.7	0.04
DHS action level constitutents[c]								
DBCP	USGS	1.0	7	0.005	<0.003	19	0.01	<0.003
Carbon tetrachloride	EPA	5.0	4	<10	<10	12	<10	<10
Tetrachloroethylene	EPA	4-40	4	<10	<10	12	<10	<10
Trichloroethylene	EPA	5-50	4	<10	<10	12	<10	<10
EPA SNARL constituents[d]								
Carbon tetrachloride	EPA	200/—[e]	4	<10	<10	12	<10	<10
Tetrachloroethylene	EPA	2,300/20[e]	4	<10	<10	12	<10	<10
Trichloroethylene	EPA	2,000/75[e]	4	<10	<10	12	<10	<10
1,1-Dichloroethylene	EPA	1,000/70[e]	4	<10	<10	12	<10	<10
Trans-1,2-dichloroethylene	EPA	2,700/—[e]	4	<10	<10	12	<10	<10
Chlordane	USGS	63/8[e]	19	0.3	<0.1	65	1.2	0.1
1,1,1-Trichloroethane	EPA	—/3,300[e]	4	<10	<10	12	<10	<10
Dichloromethane	EPA	13,000/150[e]	2	<10	<10	5	<10	<10

[a] N is the number of samples analyzed.

[b] SDWA = Safe Drinking Water Act.

[c] DHS = California Department of Health Services.

[d] SNARL = Suggested No Adverse Response Level.

[e] The first number represents a one-day average concentration and the second number represents a long-term average concentration.

All measurements of lindane, endrin, methoxychlor, silvex, toxaphene, and 2,4-D were substantially less than the SDWA criteria. Similarly, all measurements of DBCP were substantially less than the DHS Action Level. It is not possible to determine if the DHS Action Levels for carbon tetrachloride, tetrachloroethylene, and trichloroethylene are met because the action levels are lower than the detection limits for these constitutents in testing done by the EPA contract laboratories. For example, the detection limit for tetrachloroethylene is 10 ug/l, which is higher than the low end of the criterion range. None of the EPA SNARLs are exceeded at any of the sites.

Rainfall Data. Table 7-2 compares rainfall data with SDWA criteria. The maximum and median concentrations of the metals and organics which were tested are presented for the three precipitation sites. As in the case of runoff, these comparisons are not a direct indicator of water supply impacts. However, these comparisons are useful in identifying constituents of potential concern.

None of the median metal concentrations exceeded SDWA criteria. However, the maximum concentrations of lead and manganese exceeded the SDWA criteria at the single-family residential and industrial sites, and the maximum concentrations of iron exceeded the SDWA criterion at all three sites. The concentrations of lindane, methoxychlor, and 2,4-D were less than the SDWA criteria.

Soil Water and Groundwater Data. Table 7-3 presents the SDWA criteria for eight metals and the maximum and median concentrations of these constituents in the soil water and groundwater at the five recharge test basins. Approximately 10 to 20 samples were analyzed for arsenic, copper, iron, and lead. One to three samples were analyzed for the other metals. The median and maximum concentrations of these metals in both the soil water and the groundwater at the five sites are substantially less than the criteria. The maximum concentration of arsenic was 10 ug/l compared to the criterion of 50 ug/l. The maximum concentration of copper was 81 ug/l compared to the criterion of 1,000 ug/l. The maximum concentration of iron was 60 ug/l compared to a criterion of 300 ug/l. The maximum concentration of lead was 6 ug/l compared to a criterion of 50 ug/l. Based on the limited data collected, the maximum concentrations of the other metals were significantly lower than the criteria, with the exception of mercury, which was measured at a concentration half the criterion. Additional mercury monitoring should be conducted. Even if the SDWA criteria for cadmium and lead are revised downward, the concentrations in soil water and groundwater will likely still be lower than the criteria.

Table 7-2. Comparison of Precipitation Quality with Drinking Water Criteria

Constituent	SDWA criterion,[a] ug/l	Concentration, ug/l					
		Single-family residential		Industrial		Laboratory	
		Maximum	Median	Maximum	Median	Maximum	Median
Arsenic	50	<1	<1	<1	<1	1	<1
Cadmium	10	1	<1	1	<1	—	—
Chromium	50	<1	<1	<1	<1	<1	<1
Copper	1,000	6	4	12	6	8	2
Lead	50	61	8	51	7	44	5
Mercury	2	0.1	0.1	0.2	<0.1	0.1	<0.1
Zinc	5,000	60	60	90	55	30	20
Iron	300	1,400	90	2,800	130	1,300	80
Manganese	50	60	10	80	10	40	10
Lindane	4	0.02	0.01	0.04	0.01	0.01	0.01
Methoxychlor	100	0.05	<0.01	0.12	<0.01	0.04	<0.01
2,4-D	100	0.04	<0.01	0.08	<0.01	0.04	<0.01

[a] SDWA = Safe Drinking Water Act.

Table 7-3. Comparison of Soil Water and Groundwater Quality with Drinking Water Criteria

Constituent	SDWA criterion, ug/l	Sampling medium	Concentration, ug/l									
			Basin F		Basin G		Basin M		Basin EE		Basin MM	
			Maximum	Median	Maximum	Median	Maximum	Median	Maximum	Median	Maximum	Median
Arsenic	50	Soil water	4.0	<1	—	—	5.0	<1	4.0	<1	5.0	<1
		Groundwater	6.0	<1	9.0	<1	8.0	<1	10	<1	2.0	<1
Copper	1,000	Soil water	81	6.4	—	—	42	42	30	7.9	60	18
		Groundwater	16	3.0	75	20	23	2.8	11	2.0	21	3.0
Iron	300	Soil water	15	4.0	—	—	<6.0	<6.0	60	6.5	11	3.5
		Groundwater	19	3.5	21	4.0	9.0	4.5	15	7.0	7.0	1.0
Lead	50	Soil water	6.0	<1	—	—	<2	<2	3.0	<1	4.0	2.0
		Groundwater	1.0	<1	2.0	<1	6.0	<1	2	<1	<1	<1
Cadmium	10	Soil water	<1	<1	—	—	—	—	—	—	<1	<1
		Groundwater	<1	<1	<1	<1	<1	<1	—	—	<1	<1
Chromium	50	Soil water	0.5	0.3	—	—	—	—	—	—	0.4	0.4
		Groundwater	0.5	0.5	0.3	0.3	0.3	0.3	—	—	0.1	0.1
Mercury	2	Soil water	0.2	0.2	—	—	—	—	—	—	<0.2	<0.2
		Groundwater	0.2	0.2	1.0	1.0	<0.2	<0.2	—	—	0.4	0.4
Zinc	5,000	Soil water	10	<10	—	—	—	—	—	—	90	90
		Groundwater	<10	<10	20	20	20	20	—	—	20	20

As discussed in Chapter 5, soil water and groundwater samples were analyzed extensively for numerous pesticides. Diazinon was the only pesticide that was detected. Three samples of approximately a total of 80 had concentrations that were 0.3 ug/l or less. At this time, a drinking water criterion for diazinon has not been established. A few water samples were also analyzed for semi-volatile organics using EPA method 625. None of semi-volatile organics were at concentrations greater than the detection limits which ranged between 10 and 25 ug/l.

Impacts on Drinking Water

The main objective of the Fresno NURP project has been to determine the present impact of recharge of urban runoff on the quality of the groundwater supply. Future impacts have also been addressed, but at the outset of the project it was recognized that projecting future impacts would be difficult due to the complex factors influencing contaminant migration. Existing and future impacts are decribed in this section.

Present Impacts. Currently, there are no adverse impacts on the groundwater resulting from recharge of urban storm runoff to the five basins tested. Concentrations of all metals and organic compounds in the soil water and groundwater underlying the five test basins are within the SDWA criteria. It is expected that similar conditions would be found in the groundwater underlying most of the other recharge basins in the District. However, basins serving areas with considerable industrial development may pose a greater threat to the groundwater. While runoff quality was tested by this project at such a site, the basin soils, soil water, and groundwater were not tested and should be the object of future monitoring.

The analysis of data presented in Chapter 5 indicated the possibility that some contaminants may be migrating through the soil layer, particularly in Basin MM with its sandy profile. However, there is no evidence of any accumulation of these compounds in the underlying groundwater. From the standpoint of mineral quality (common cations and anions), recharge of urban storm runoff and summer irrigation water is improving the regional groundwater quality, since the mineral quality of the water being recharged is better than the regional groundwater quality.

Future Impacts. The two main factors that will influence the future effects of recharging storm runoff are (1) changes in the volume and quality of urban runoff and (2) changes in contaminant reduction mechanisms now occurring in the soil layer. Each of these key factors is discussed below.

The recharge basins will continue to receive a load of each constituent each year when the storm runoff enters the basins during the rain season. If soil is not removed from the basins, the accumulated load will increase each year. For example, about 18 percent of the Basin F watershed is currently undeveloped so there is some potential for increased annual loads to this basin. Other watersheds served by District recharge basins are also undergoing development and new areas are being provided with drainage and recharge facilities.

There may also be changes in the quality of runoff water due to changes occurring at the contaminant source. Lead is the best example and is an important issue, since lead is one of the contaminants of most potential concern. Based on the data presented on Figure 6-2, it is clear that the runoff loading rate of lead will continue to decrease in the future as the number of cars which use leaded gasoline decreases. Changes in pesticide use practices may also alter runoff quality. For example, there are now restrictions on the use of some pesticides such as chlordane, which will decrease the amount of these pesticides reaching the recharge basins. Currently, chlordane is used exclusively for subterranean termite control by licensed pest control operators. According to the California Department of Food and Agriculture records, chlordane use in Fresno County is less than 10 percent of that used during the 1970s.

The various mechanisms affecting contaminant migration in soils were reviewed in Chapter 5. Numerous physical, chemical, and biochemical processes influence the contaminant mobility. These processes are affected by certain soil properties, including soil texture, cation exchange capacity, pH, oxygen, and organic matter. These properties are unlikely to change unless modifications are made either to the basins or to current operating practices. However, the key question is whether the removal capabilities of the soil layer will become depleted over time, if current basin operations are maintained. The fact that some of the District's basins (e.g., Basins F and G) have been operated for about 20 years provides some perspective on this question. A reduction in contaminant removal capability, if it occurs at all, will happen gradually. Levels of lead and the other metals in the basins tested are currently several times less than SDWA criteria. None of the organics for which criteria exist have even been detected. Thus, there is a significant margin of safety at present. It is unlikely that recharge will cause adverse impacts on the groundwater supply in the near future for the type of recharge basins evaluated in this study. Continued monitoring of the groundwater underlying the recharge basins would detect changes in groundwater quality well in advance of a problem occurring. However, the potential impacts on groundwater underlying basins serving industrial areas may be somewhat greater.

Because of the importance of protecting the sole source aquifer in the Fresno area, present operational practices of the retention/recharge system should be carefully reviewed to be certain that the risk of adversely affecting the groundwater supply continues to be minimized. Operational and management practices are reviewed in Chapter 8.

RECREATIONAL IMPACTS

Presently 13 of the District's 74 completed basins are available for recreation. Three of these basins have improved baseball diamonds, while the other nine are used for soccer and passive recreation. During these activities, contact with basin soils can occur. Thus, the potential for adverse impacts on recreation has been evaluated. Criteria for various contaminants in soils have been considered in assessing impacts on recreational use.

Soil Criteria

Criteria have been developed by the DHS, Hazardous Waste Management Branch, to determine whether or not waste materials containing metal and organic contaminants are hazardous. They are documented in "A Summary of the Draft California Regulatory Wastes", October 1982. We have discussed with DHS the applicability of these criteria to stormwater recharge basins. DHS staff members indicated that since accumulation of contaminants in recharge basins is not being caused by any specific source and is really a nonpoint source situation, it does not fall under their toxics enforcement program. However, if the material in the recharge basins were to be removed and disposed of, the hazardous waste regulations would then be applicable. DHS staff also stated that if there are levels of contaminants in the basin soils that exceed DHS criteria, DHS would be concerned about potential health impacts and would encourage reasonable management practices to alleviate the potential problem. Based on this guidance received from DHS, we believe it is appropriate to use DHS criteria as a basis for assessing the conditions in the recharge basins.

The DHS soil criteria are presented for soluble materials, expressed as a Soluble Threshold Limit Concentration (STLC), and for solid materials, expressed as a Total Threshold Limit Concentration (TTLC). Because of the nature of soil and plant tissue samples analyzed in this study, and the complete digestion method of analysis used to determine contaminant concentrations in the samples, the TTLC values established by the DHS are appropriate to use for initial evaluations. Data on metal and organic concentrations from regular samples for the five test basins summarized in Chapter 5 are presented in Table 7-4 along with TTLC values for comparison. The following observations can be made:

1. Maximum lead and chlordane concentrations measured in the soil surface (0.00 to 0.02 m) were above TTLC values. Median concentrations were less than TTLC values.

2. Maximum and median surface concentrations of the other metals and organic contaminants were less than TTLC values.

3. Concentrations of all metal and organic contaminants averaged over the surface 0.3 m of the soil column were well below TTLC values (on the order of 1/100th of TTLC values).

The data contained in Table 7-4 are based on soil sampling at a single point in each of the five test basins. The data collected in the spatial survey for lead conducted in Basins F and B/E (see Figure 5-4) provides an indication of how concentrations vary over the entire basin surface. The highest lead concentrations occurred in low spots or close to the outfalls. Cores of the upper 8 cm of soil were collected in the spatial survey. Concentrations for the 0 to 2 cm depth can be estimated using soil profile data collected in this project. It is estimated that the mean and maximum lead concentrations in the 0 to 2 cm depth for the spatial survey would be as follows:

Basin	Lead concentration, mg/kg	
	Mean	Maximum
Basin F		
Upper recreation basin	670	2,500
Lower recharge basin	420	1,600
Basin B/E		
Upper recreation basin	210	2,300
Lower recharge basin	3,500	6,800

The spatial survey data clearly show that there are localized areas within the recreation basins that significantly exceed the TTLC for lead. The highest lead concentration occurred in the low-flow basin in Basin B/E. The low-flow areas in both basins are fenced off and are not used for recreational purposes.

Table 7-4. Comparison of Toxic Constituent Concentrations in Soil Samples with Hazardous Wastes Criteria

Constituent	Sample depth, meters	Concentration[a], mg/kg				TTLC,[b] mg/kg
		Control samples		Basin samples		
		Median	Maximum	Median	Maximum	
Arsenic	0.00 - 0.02	5.4	12.0	11.5	48.0	500
	0.24 - 0.30	2.0	3.2	3.4	8.4	
	2.7 - 3.0	2.5	4.9	2.6	28.0	
Nickel	0.00 - 0.02	20.0	35.0	35.5	83.0	2,000
	0.24 - 0.30	10.0	45.0	10.5	42.0	
	2.7 - 3.0	9.2	23.0	8.2	190.0	
Copper	0.00 - 0.02	16.0	49.0	26.5	79.0	250
	0.24 - 0.30	8.2	25.0	5.4	15.0	
	2.7 - 3.0	13.0	17.0	6.1	49.0	
Lead	0.00 - 0.02	37.0	107.0	740.0	1,600.0	1,000
	0.24 - 0.30	5.1	5.6	6.2	28.0	
	2.7 - 3.0	2.9	6.7	2.6	8.9	
Mercury	0.00 - 0.02	—	—	0.07	0.10	20
Chlordane	0.00 - 0.02	<0.03	<0.03	0.93	2.90	2.5
	0.24 - 0.30	<0.03	0.04	<0.03	<0.03	
	2.7 - 3.0	<0.03	<0.03	<0.03	<0.03	
Lindane	0.00 - 0.02	<0.01	<0.01	<0.01	0.02	4.0
	0.24 - 0.30	<0.01	<0.01	<0.01	<0.01	
	2.7 - 3.0	<0.01	<0.01	<0.01	<0.01	
DDT,DDE	0.00 - 0.02	<0.03	<0.03	<0.03	0.47	1.0
	0.24 - 0.30	<0.03	<0.03	<0.03	<0.03	
	2.7 - 3.0	<0.03	<0.03	<0.03	<0.03	
PCB	0.00 - 0.02	—	—	0.30	0.43	50

[a] Based on samples from all five test basins.

[b] Total threshold limit concentration.

The TTLC of 1,000 mg/kg for lead is for inorganic lead. Apparently, organic lead is much more toxic and thus has a much lower TTLC, 13 mg/kg. Several samples in the spatial survey were checked for organic lead. All samples were less than 1 mg/kg.

Soils samples were not collected from any basins that receive significant drainage from industrial areas. In the runoff monitoring program, USGS did monitor runoff from an industrial area. As reported in Chapter 4, runoff concentrations of several of the heavy metals were higher at the industrial site than the other three sites. It is likely that the concentrations of these metals in the basin soils would be similarly higher.

Impacts on Recreation

Assessing the impacts of contaminated surface soils in recharge basins on recreation is considerably more difficult than assessing the impacts of runoff on groundwater. The drinking water criteria have evolved through extensive research conducted over the past few decades. The DHS soils criteria have been developed quite recently as part of the program to manage hazardous wastes and are continuing to be refined as further research is conducted. Although DHS soil criteria do not directly apply to the recharge basin situation, they are a useful means for judging the relative magnitude of the problem.

Present Impacts. Of all the constituents evaluated, the only two constituents of any real concern are lead and to a lesser degree, chlordane. The primary health impact of these contaminants is through ingestion of soil by children. The potential for soil ingestion during activities in the recreational basins is quite limited, since most of the area is turfed. The infield area in the baseball diamonds is the only significant unturfed area and this soil is periodically removed as part of park maintenance. There are children's playgrounds at some of the recreational basin sites. However, these facilities are located along the outer perimeter of the basin which does not normally receive recharge water.

A second method by which health effects could occur is through dust inhalation. Discussions with DHS staff indicate that inhalation of contaminants such as lead in this situation is of less concern than ingestion. It is difficult to quantitatively estimate the concentrations of contaminants that would be present in the air if the soil in a recharge basin is disturbed. Using a set of fairly conservative assumptions, we have computed the potential atmospheric lead level. Using the maximum lead soil concentration of 1,600 mg/kg, we estimated that dust created from disturbing bare soil would contain a lead concentration in the air of 16 ug/m^3. The OHSA standard for lead exposure for an eight hour occupational exposure is 50 ug/m^3. Thus, the estimated lead level is well within the standard that OSHA uses for worker exposure. The potential risk would be further reduced due to the much shorter exposure period that would occur during recreational activities as compared to continuous worker exposure.

The comparison of soil contaminant concentrations with the soil criteria indicates some potential concern with lead levels. The potential for significant ingestion of soil is remote given the relatively small unturfed area in the recreational basins and the fact that the unturfed areas are not normally used by small children. However, a potential problem does exist, and the District should manage and operate the basins in a manner that minimizes the health risk. These issues are further discussed in Chapter 8.

Future Impacts. Future impacts on recreational use will be affected by runoff loading changes, as discussed in the section on drinking water impacts. The runoff concentrations of the two constituents of primary concern to recreation, lead and chlordane, have been decreasing and will continue to decrease in the future. A reduction in the number of automobiles using unleaded gasoline will reduce lead concentrations in runoff. The restricted use of chlordane will similarly reduce chlordane concentrations in runoff as compared to historic levels. Thus, the impacts of soil contaminants on recreation are not likely to increase in the future.

CHAPTER 8

MANAGEMENT PRACTICES

The Nationwide Urban Runoff Program (NURP) was designed to evaluate a range of best management practices for dealing with stormwater runoff. Each NURP project analyzed one or more specific management practices. Several projects evaluated the effectiveness of street sweeping. Other projects investigated catch basin cleaning, detention basins, grassed swales, overland flow wetlands, and other treatment methods. The management practice being tested in the Fresno NURP project is the use of recharge basins as a method for management of stormwater. Thus, the existing system of retention/recharge basins has served as a management practice, in contrast to many of the other projects where special facilities were constructed and operated or where drainage and runoff conditions were controlled to test a particular methodology.

This chapter evaluates the current operation of the retention/recharge system in view of the results found in this investigation. Since our assessment concluded that there is some potential for adverse environmental impacts, several modifications to the present operation and some source control methods are also discussed.

CURRENT PRACTICE

Stormwater management in the Fresno metropolitan area is complicated by the fact that there are no significant watercourses passing through the area to which storm runoff can be discharged. Therefore, the Fresno Metropolitan Flood Control District (District) has developed a system of retention/recharge basins to handle runoff during storm periods. The system has a dual purpose: it services drainage needs, and at the same time water is recharged to the groundwater, which is the sole source of water supply for the region.

The District currently has 74 basins that are completed or are in various stages of excavation. The land has been purchased for twelve additional basins. More basins will be added to the system as new areas develop. Key features of the existing basins are summarized in Table 8-1. The table includes all acquired basin sites that will, in the future, be used for recreation, have a low-flow area, or have on-peak pumping relief.

Table 8-1. Features of Existing Retention/Recharge Basins

Basin feature	Number of basins[a] Existing recreation	Future recreation	Non-recreation	Total
All basins	13	37	36	86
Existing turfed basins	13	0	1	14
Low-flow area				
Existing	10	13	2	25
Future	0	23	3	26
Existing pumpout capability[b]				
To canal	5	2	3	10
To another basin	3	2	2	7
Proposed pumpout capability				
To canal	(1)[c]	2	4	5
To another basin	4	3	7	14
More than half of drainage area is zoned industrial	1	5	15	21

[a] Includes all basins acquired to date of this report.

[b] Pumpout capability refers only to those basins requiring on-peak pumping.

[c] The water from one basin that is currently pumped to a canal will be pumped to another basin when construction of the basin is completed.

There are two primary types of basins: turfed and unturfed basins. There are 14 turfed basins, and 13 of these basins are used for recreation during the dry weather season. Three of the turfed basins have improved baseball diamonds, while the other turfed basins are used for soccer and passive recreation. The remaining 73 basins are currently unturfed and are used strictly for recharge. A number of the non-recreational basins also receive irrigation water from the Kings River during the summer for recharge. Kings River water is diverted into the Fresno Irrigation District canal system and is then conveyed into the recharge basins that are located adjacent to the irrigation canals. As much as 12,000 acre-feet of irrigation water is recharged annually.

There are two particular features of some of the recharge basins that significantly affect system operation and in turn have important water quality implications: the low-flow basin and pumpout capability.

Low-Flow Basin

Twenty-five basins now have a low-flow basin at the recharge site. There are plans to provide an additional 26 basins with a low-flow area. The low-flow basin is generally at least 10 feet below the elevation of the upper basin. The low-flow basin concept was primarily developed for use with the recreational basins. During the summer, runoff water from lawn sprinkling, or nuisance runoff, that enters the drainage system can be contained in the small low-flow basin. Thus, it is possible to keep the upper basin dry and available for recreation.

During the winter, the low-flow basin receives runoff water first. As the low-flow basin fills, the influent drainage pipe will surcharge and water will eventually back-up and flow into the upper basin. Thus, in small winter storms, the low-flow basin may capture a large portion of the storm volume. The exact volume that the low-flow basin can handle will depend on the recharge characteristics as well as the design size of the specific basin.

The low-flow basin is very important from a water quality standpoint. As discussed in Chapter 4, many contaminants in storm runoff are at their highest concentrations during the beginning of a storm when the "first flush" occurs. Thus, the most concentrated material is contained in the low-flow basin, while the flow reaching the upper recreation basin is considerably less contaminated.

In Chapter 4, a tabulation of the portion of the metals in runoff occurring in the particulate and dissolved forms was developed (Table 4-9). The particulate fraction of most metals was generally much larger than the dissolved fraction. For example, more than 75 percent of the aluminum, chromium, iron, and lead was in the particulate form at all four sampling sites. Thus, it would be expected that metals concentrations in the surface soils in the low-flow basin would be higher than the levels found in the upper basin. The results of the spatial lead survey presented on Figure 5-4 confirm this relationship. In Basin B/E, lead concentrations in the soil of the low-flow basin were at least several times higher than the concentrations in the upper basin. This difference in lead concentration did not occur in Basin F, probably because there is only a 2-foot differential in elevation between the upper and lower basins.

Some of the low-flow basins, as well as other recharge basins in the system, have man-made sandy recharge areas. These areas were added to increase the recharge rate. However, these sandy soils are less capable of removing most contaminants than soils with a higher proportion of silt and clay or soils with more organic material.

Pumpout Capability

Fifteen basins now have, or there are plans to provide, capability to pump runoff water on peak from the basin into a nearby irrigation canal. For 21 other basins, on-peak runoff can now be pumped, or will be able to be pumped in the future, to another recharge basin. Pumping has been provided to improve flood control capability and facilitate dewatering. The extent of pumping is limited by the available capacity in irrigation canals and other District basins to which flow can be transferred. Generally, pumps are activated as soon as runoff reaches the basin. There are no records of the pumping volumes, but District staff indicate that the portion of the runoff that is pumped out can range from as little as 1 percent in Basin MM to as much as 20 percent in Basin F.

Like the low-flow basin, on-peak pumping has significant water quality implications. If pumping is initiated when runoff first occurs, the "first flush" material with the highest contaminant concentrations is being removed, although some material may settle to the basin bottom. This material is either being transferred to another basin or is being conveyed to irrigation canals. The potential impact of the water pumped from the recharge basins to the irrigation canal system has not been evaluated as part of the Fresno NURP project.

Other Operational Practices

The District now removes deposited material from the basins on an as-needed basis. A number of the basins have periodically had material removed primarily for the purpose of improving the recharge rate. For example, the low-flow area in Basin M has been dewatered and cleaned out on two occasions during the 15 years it has been in operation. The material removed has generally been used for fill on site in the freeboard area or on nearby lands.

The unturfed basins that receive summer irrigation water have sometimes been subject to surface sealing of the basin bottom due to erosion of fine material from the side slopes. Therefore, these basins are scraped approximately once per year to improve percolation. In addition, the side slopes are disked for weed control.

MODIFIED PRACTICES

The impacts of the current operation of the retention/ recharge system were discussed in Chapter 7. In terms of the groundwater underlying the five basins tested, stormwater recharge has had no adverse effects. All measurements of soil water and groundwater were within the drinking water standards. However, no groundwater measurements were made at basins receiving a significant amount of drainage from industrial areas. Runoff in these two cases theoretically would pose a greater threat to the groundwater than the five basins which were sampled.

In terms of recreational uses of the basins, quantifying impacts are difficult. The Department of Health Services (DHS) soil criteria for hazardous wastes can be used as a general guideline. Comparison of surface soil concentrations with these soil criteria indicates that in localized areas (low spots, near outfalls, and in the low-flow basins) there are some surface soils that exceed the DHS criteria for lead and chlordane. The significance of these concentrations is uncertain, since exposure is minimal due to the turf layer in the recreational basin.

Although there are no apparent impacts on water supply and the significance of the limited violations of the soil criteria are uncertain, some modifications to the District's current system procedures are warranted to insure a future which continues to be free of impacts. Certain operational modifications and management practices can be implemented to minimize the risk of future impacts. This section describes modifications to current practices, and the next section describes source controls.

Table 8-2 summarizes the management practices that have been evaluated. The following basin modifications have been considered:

1. Providing additional low-flow basins.
2. Removing basin soils.
3. Providing additional pumpout capability.
4. Turfing unturfed areas.

The need for continued monitoring is identified in Table 8-2. Recommended areas of future monitoring are delineated in Chapter 9.

Low-Flow Basins

The low-flow basin concept provides an excellent means of containing the "first flush" from urban runoff. Twenty-five recharge sites now have low-flow basins. Additional low-flow facilities should be provided in two particular situations. First, any recreational basins that do not currently have a low-flow basin should be provided with one. This will provide considerable protection for the portion of the basin that is

Table 8-2. Alternative Management Practices

Practice	Needed to protect		Purpose	Advantages and disadvantages	Recommendation
	Drinking water	Recreation			
I. Basin Modifications					
A. Add low-flow basin to all present and future recreation basins.		X	"First flush" will go to low-flow basin. Thus, contaminant concentration in recreational basin will be lower.	Practical to provide since low-flow basins are also desirable to prevent summer irrigation runoff from entering recreational basin.	This measure is highly cost-effective and should be implemented.
1. Periodically cleanout solids accumulation.	X		Cleaning will reduce potential leaching of concentrated material to groundwater.	Material will have to be hauled to hazardous waste disposal area.	Periodic basin cleaning should be done on a frequency dictated by periodic sampling and buildup curve data.
B. Provide low-flow basin for areas with significant industrial development.			Provide means of containing potentially hazardous material.	These measures are highly desirable to protect against a significant potential hazard.	Implement.
1. Periodically cleanout solids accumulation.	X		Prevent percolation of hazardous material.	These measures are highly desirable to protect against a significant potential hazard.	Implement.
2. Line low-flow basin if warranted based on soil and water sampling data.	X		Prevent percolation of hazardous material.	Expensive, so should be based on sampling results and compared to upstream source controls.	Assess the need on a case-by-case basis
C. Seal off recharge wells located in low-flow basins.	X		Prevent percolation of hazardous material.	Some loss in recharge capability. Desirable to protect water supply.	Implement.
D. Periodically remove surface soils from all basins.	X	X	Remove contaminants that may leach to groundwater.	High cost (approximately $50,000 per basin). May be removing organic material that helps remove contaminants.	Implement for recreational basins only in accordance with additional soils sampling.
E. Periodically remove solids that deposit near outfalls in recreation basins.	X	X	Remove material that is likely to have highest contaminant levels.	Could be easily added to annual maintenance of basins, although disposal would be to hazardous waste disposal site.	Implement.

Table 8-2. Alternative Management Practices, continued

Practice	Needed to protect		Purpose	Advantages and disadvantages	Recommendation
	Drinking water	Recreation			
F. Provide ability to pump out low-flow basin to irrigation canal where location allows.	X	X	Prevent "first flush" material from accumulating in recharge basins.	Not desirable to pump out "first flush" material since this would just move the material to downstream waters.	Evaluate ways of modifying pumping operation to minimize "first flush" pump-out.
G. Turf all unturfed basins.	X		Improve contaminant removal capability.	Cost would be significant. There may be some reduction in percolation rate.	Not justified at this time.
H. Turf unturfed areas of recreational basins or remove soil regularly.		X	Minimize opportunity for solids ingestion and inhalation.	Minimal cost. Turfing baseball diamonds would lessen desirability to play.	Implement regular soil removal based on contaminant buildup curve.
II. Source Controls					
A. Late summer street sweeping.	X	X	Remove street accumulation prior to initial fall storms.	Other NURP projects had mixed opinions of effectiveness of street sweeping. Current sweeping in the metropolitan area is quite limited.	Not recommended except as an incremental benefit of any sweeping done for aesthetic purposes.
B. Have industry contain and/or pretreat runoff from portions of their site that may contain toxic material.	X		Remove contaminants at the point of origination.	Requires monitoring to be sure upstream controls are working.	This approach should be adopted as a policy, but implemented on a case-by-case basis in accordance with sampling data.
III. Monitoring					
A. Long-term monitoring of basin soils and groundwater.	X	X	Early detection of contaminant buildup.	Essential to environmental protection.	Implement.
B. Hazardous spills.	X	X	Prevent contaminants from reaching basins.	Highly desirable to protect against potential health hazard.	Participate in county spill control program.

used for recreation. Secondly, a low-flow facility should be provided or more frequent basin cleaning should be implemented in drainage areas where a significant amount of the contributing area will be developed for heavy industrial purposes (e.g., chemical storage or transfer, petroleum, and some manufacturing operations). In terms of existing basins serving industrial areas, the need for a low-flow basin should be assessed by either a detailed field inspection of the land area or a runoff monitoring program. In some industrial situations, it may be necessary to provide the low-flow basin with a protective lining, so industrial contaminants will not percolate into the groundwater. The need for lining should be based on runoff monitoring.

The solids accumulations in the bottom of the low-flow basins should be periodically removed to prevent the leaching of this concentrated material into the deeper soils and ultimately to the groundwater. It is likely that concentrations of some constituents in the soil will exceed DHS soil criteria and, therefore, the soil will have to be hauled to a hazardous waste disposal site. Alternatively, the material could be removed and used as fill material before it reaches hazardous levels. Consideration should also be given to sealing off recharge wells in low-flow basins.

Removing Basin Soils

The sampling conducted in this project showed that many of the metals and organic compounds present in urban runoff were detected in the surface soil layer in the recharge basins. Lead and chlordane were the only two constituents that were found to exceed the DHS soil criteria in a limited number of samples. The spatial survey performed in Basin F gives a good indication of the distribution of lead in the surface soils. Figure 8-1 denotes the areas within the basin where the lead concentration exceeded the DHS total threshold limit concentration (TTLC) for lead. Approximately 1 acre or about 16 percent of the combined area of the upper and lower basins had lead concentrations that exceeded the TTLC. An elevation profile for this basin was presented in Chapter 5.

Based on the lead distribution on Figure 8-1, a preliminary estimate of the cost to remove the contaminated soil has been prepared to illustrate the range of cost for this management practice. Costs were developed for two alternative methods of soil removal. The first alternative deals only with the affected areas down to the depth where the lead exceeds 1,000 mg/kg. Costs include excavation, hauling, disposal (as hazardous waste), refill, leveling, sprinkler installation, and revegetation. Construction cost by this method would be about $20,000. It is probably not practical to excavate such exact

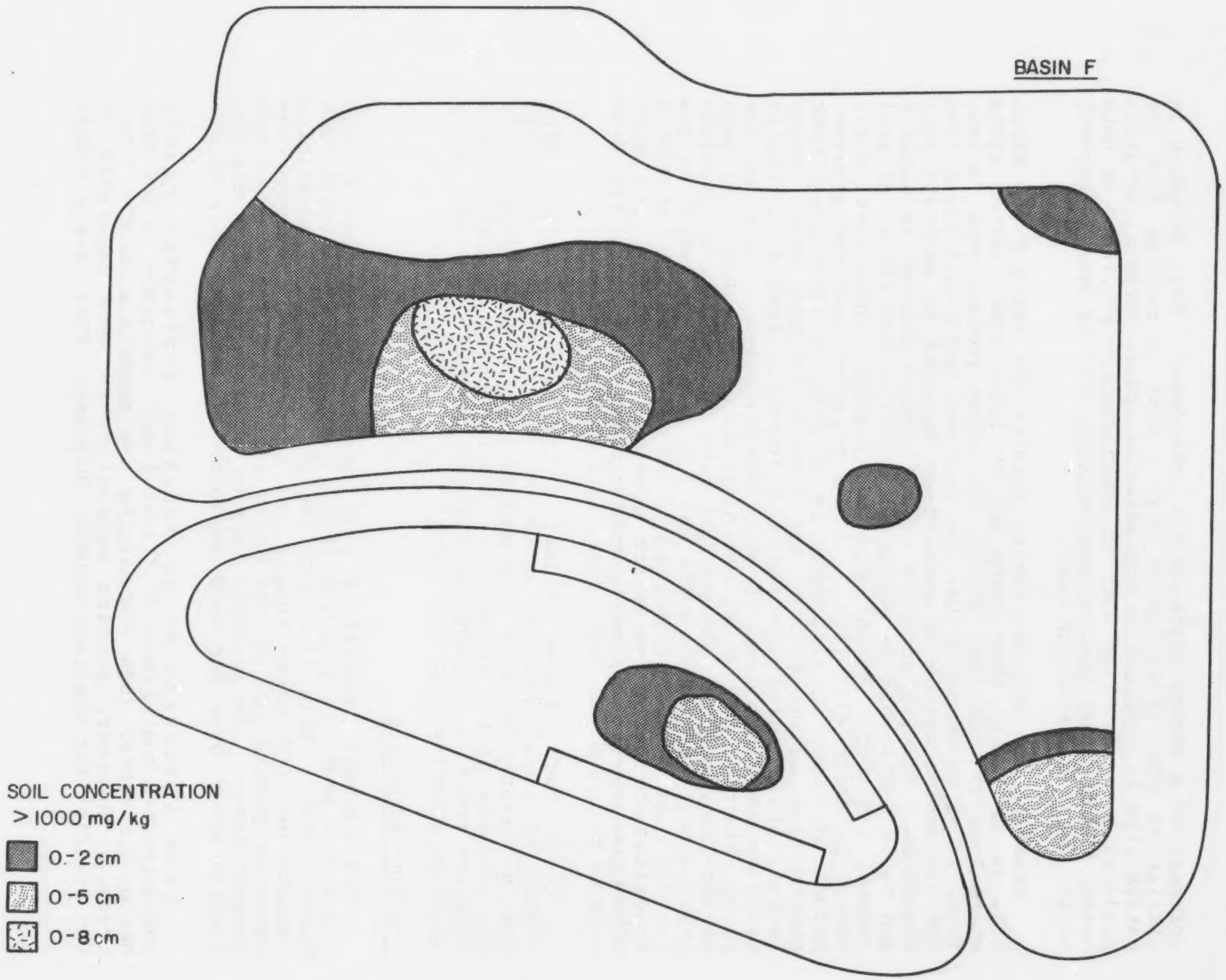

Figure 8-1 Comparison of Lead Concentration with Soil Criterion

volumes, so a second approach was considered. This approach is similar to the first, except that 1 inch is removed from the entire site in addition to the affected areas. This alternative produces a construction cost of approximately $75,000. In both cases, the disposal cost of contaminated soil is over 50 percent of the total construction cost.

Based on the spatial survey results for Basin F and Basin B/E, it is likely that there are at least some limited areas where lead exceeds the TTLC in the other recreational basins. Thus, it is recommended that the turf and upper soil layer from the recreation basins be removed as required to maintain soil standards. Spatial sampling of the type conducted in Basin F and Basin B/E should be performed to define the extent of soil removal required. Basins with the highest contaminant levels should be dealt with first. It is expected that the greatest amount of material will have to be removed from the oldest recreational basins that do not have a low-flow area. Newer recreational basins that have a low-flow area will likely have the smallest areas of soil contamination. Based on the sharp reduction in the use of chlordane and the amount of lead in gasoline, the two elements of most concern, it is possible that removal of surface soils may not be required again in the future. It would be prudent to study basin maintenance practices to determine which scraping techniques are most effective in removing basin contaminants, and which are best able to remove silts, and, thus, improve percolation.

We do not believe removal of surface soils from non-recreation basins need be mandatory at this time. There has been no deterioration of groundwater quality underlying any of the recharge basins tested. If future monitoring indicates a downward trend in groundwater quality, removal of surface soils could be considered at that time.

Pumping Capability

The pumpout capability that now exists in some basins provides a means of removing "first flush" runoff material from those basins. This is a positive step in terms of minimizing impacts on both water supply and recreation. However, the material pumped out of the basin eventually reaches the San Joaquin River. The possible impacts of urban runoff on the San Joaquin River have not been evaluated as part of this study.

From a standpoint of managing stormwater runoff contaminants, containment of "first flush" materials in low-flow basins is better than discharging the materials to the river system. However, pumping capability is very important to the District for drainage control purposes. There are a number of ways that current pumping operations could be modified to reduce potential downstream impacts. The pump intake could be raised or pump settings could be adjusted, so that the first flush material is not pumped. A dual-compartment basin could be designed in future basins. Flow would enter the first basin and then overflow into the second basin. "First flush" solids would accumulate in the first basin, and runoff water could be pumped out of the second basin. Further evaluation of the engineering design features of future recharge basins is needed before specific modifications can be recommended.

Additional Turfing

Turfing over unturfed areas at recreational basins would reduce the potential for public contact with contaminants present in surface soils. Alternatively, the surface soil layer could be periodically removed, since the unturfed areas are quite small. The frequency of removal should be based on periodic monitoring to define contaminant buildup curves.

SOURCE CONTROLS

There are two source control measures that have been considered: street sweeping and upstream controls at industrial areas.

Street Sweeping

Street sweeping was not evaluated as part of the Fresno NURP project. Limited street particulate data were collected at the four U.S. Geological Survey (USGS) sites which indicated the presence of most heavy metals and several organic constituents. Five of the 28 NURP projects had the evaluation of street sweeping as a central element of their work plans. These projects were at the following locations: Castro Valley, California; Milwaukee, Wisconsin, Champaign-Urbana, Illinois; Winston-Salem, North Carolina; and Bellevue, Washington. Four of these projects concluded that street sweeping was not effective as a management practice to control pollutants in urban runoff. The fifth project (Castro Valley), which has pronounced wet and dry seasons, showed that sweeping just prior to the rainy season could produce some benefit. However, the Final NURP Report by the U.S. Environmental Protection Agency cautions that even in areas with distinct wet and dry seasons, the effectiveness of street sweeping should be closely evaluated on a case-by-case basis.

Since Fresno does have distinct wet and dry seasons, street sweeping in the late summer or early fall could possibly provide some benefit. The current street sweeping program in the

Fresno-Clovis metropolitan area is fairly limited. Because of the uncertainties of street sweeping effectiveness, it would probably not be worthwhile to expand the existing street sweeping program in Fresno for the sole purpose of urban runoff pollutant control. Current sweeping done for aesthetic purposes in the late summer or early fall may provide some limited water quality benefit.

Industrial Controls

The runoff sampling conducted by USGS indicated that for many constituents the concentrations were highest in the runoff from the industrial site. This is not surprising since there are numerous potential contaminant sources in this industrial area which included cotton mills, food processing, petroleum operations, chemical storage, carpet manufacturing, and light trucking. Without additional monitoring, it is impossible to determine the exact source of the various contaminants detected in the runoff.

Industrial areas, such as the one studied in this program, are the most significant potential source of urban runoff contaminants. As recommended previously, the District should provide a low-flow basin at all recharge sites that receive a significant amount of industrial drainage, or existing basins should have soils regularly removed. In addition, consideration should be given to having industries contain or pretreat runoff from portions of their site that may contain toxic material. Decisions to have upstream source control provided at industrial sites need to be developed on a case-by-case basis, since the types and magnitude of contaminants from industrial sites can vary widely. Additional runoff monitoring at existing industrial sites should be conducted cooperatively between the District and the Central Valley Regional Water Quality Control Board.

With regard to future industrial development, the District should work together with other local agencies (e.g., planning and building departments) to be certain that water quality aspects are adequately considered in the review process for industrial developments. In this way, provisions can be made to control potential runoff contaminants at the source.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are based on the work conducted for the Fresno Nationwide Urban Runoff Program (NURP) project.

CONCLUSIONS

Conclusions are presented in three groups: urban runoff, soils and groundwater, and impacts on water supply and recreation.

Urban Runoff

The following conclusions are based on the results presented in Chapter 4.

1. Urban storm runoff contains significant levels of many contaminants including most heavy metals and some organic compounds.

   All of the priority pollutant metals except cyanide and 19 of the 34 organic constituents tested were detected in at least one runoff sample. Constituents which have runoff concentrations significantly higher than the regional groundwater include lead, zinc, copper, mercury, iron, and manganese.

2. Urban storm runoff is better in quality than the Fresno regional groundwater for some constituents, particularly minerals and nutrients.

   The runoff concentrations of most of the common cations and anions that were measured are less than the concentrations in the regional groundwater. For example, the mean specific conductance in runoff from the residential and commercial sites is about 70 umhos/cm compared to a mean of over 300 umhos/cm in 46 city of Fresno wells. Thus, from the standpoint of mineral quality, recharge of urban storm runoff is improving the regional groundwater quality.

3. Rainfall contributes a significant portion of the pesticides measured in runoff.

   Fourteen organic compounds, including 11 pesticides, were detected in rainfall samples. The most prevalent pesticides were parathion, malathion, and diazinon. Their presence in rainfall is probably due to their use in the agricultural area around Fresno. These pesticides are present in low concentrations and none of them have shown up in the groundwater underlying the recharge basins, except traces of diazinon in a few samples.

4. The industrial area had the worst runoff quality of the four land use types evaluated.

   For the 62 non-pesticide constituents monitored, concentrations were statistically highest in runoff from the industrial site for all but 10 constituents. Concentrations in the industrial runoff fluctuated greatly during storms, and numerous unexplained concentration spikes were monitored. Concentrations at the other three sites (single-family residential, multiple-family residential, and commercial) were very similar for most constituents.

5. Runoff concentrations over the course of a storm event at the non-industrial sites followed the traditional "first flush" concept.

   The highest concentrations for most constituents from the non-industrial sites occurred during the initial storm runoff and then decreased throughout the remainder of the storm, independent of hydraulic conditions. Metal concentrations were also high during initial runoff, but also increased as flow increased.

6. There are significant seasonal variations in runoff quality that must be considered in developing management practices.

   The event mean concentration (EMC) for most constituents for all but the industrial site was highest for the first two or three storms of the year. The EMC was then relatively constant for the remainder of the rain season. (The term EMC refers to either a flow-weighted composite sample or a flow-weighted calculation of sequential discrete samples.) The EMCs at the industrial site were generally high for the first storm, but then declined uniformly throughout the rain season. This seems to indicate that an entire rain season is required to wash off dry season pollutant buildup from the industrial site, while wash off occurs during the first two or three storms at the other sites.

Soils and Groundwater

The following conclusions are based on the results presented in Chapter 5.

1. During recharge, basin soils provide a high degree of removal of storm runoff contaminants, thus protecting groundwater quality.

   Heavy metals and organic compounds present in runoff appear to be removed by basin soils, although there is some limited evidence of migration of some metals to deeper soils. No contamination of soil water or groundwater underlying the recharge basins has occurred in any of the five basins studied. The concentrations of all heavy metals in groundwater samples were similar to the levels found in the regional groundwater quality. None of the pesticides and other organic compounds, for which water samples were analyzed, were detected except diazinon which was found in trace amounts in three samples. This means that any other organic compounds, if they were present at all, were present at levels less than the analytical detection limits employed. Detection limits for specific compounds are listed in Appendix B.

2. Contaminants accumulate in the surface soils and lead concentrations vary spatially as a function of basin topography and outfall locations.

   The surface distribution of lead was determined through a spatial survey of two recharge basins. The highest lead concentrations occurred at low spots in the basin close to the basin outfalls. In the basin that has a low-flow area located 20 feet lower than the upper basin, lead concentrations in the soil were several times higher in the lower basin. Spatial surveys of other metals were not conducted.

3. Recharge of imported surface water is not presently having any adverse effect on groundwater quality, although some leaching of the basin soils is occurring.

   Imported surface water from the Kings River, which is recharged in a number of basins during the spring and summer months, is of excellent quality and thus improves the regional groundwater quality. The soil data were analyzed to determine whether the movement of large volumes of water could be leaching any compounds from the soils. For most of the cations and anions, concentrations tended to be slightly less in basins receiving summer recharge, possibly indicating some leaching. Comparison of soils samples collected before and after the summer recharge period indicates the possibility of some slight downward migration of lead due to summer recharge. Additional data are needed to confirm whether this is true.

4. There appears to be a correlation between the degree of removal of metals and the proportion of silt plus clay and organic matter in the surface soils.

   Soils containing a higher percentage of silt plus clay and organic matter have higher cation exchange capacities and should be able to better attenuate migrating contaminants. This appears to be true in the basins studied, although it cannot be conclusively proven because of variations in basin age and the fact that the two unturfed basins evaluated are the ones that receive summer irrigation water.

Impacts of Runoff

The following conclusions are based on the results presented in Chapter 7.

1. Currently, there are no apparent adverse impacts on the groundwater resulting from recharge of urban storm runoff.

   Concentrations of all metals and pesticides in the soil water and groundwater underlying the five test basins are within the Safe Drinking Water Act criteria. Two of the basins tested have been in operation for more than 20 years. Similar water quality conditions are probably present in most of the other recharge basins operated by the Fresno Metropolitan Flood Control District (District). However, one situation where storm recharge could pose a potential threat to the groundwater was not evaluated in this program: a basin serving an area that has a significant amount of industrial development.

2. It is unlikely that recharge to basins similar to those tested in this program will cause adverse impacts on the groundwater supply in the near future.

   Levels of heavy metals are currently several times less than SDWA criteria, and none of the organics for which criteria exist were ever detected. Thus, there is a significant margin of safety at present. Continued monitoring of the groundwater underlying the recharge basins would detect changes in groundwater quality well in advance of a problem occurring.

3. Lead levels in the surface soils of localized areas in some of the recharge basins exceed Department of Health Services (DHS) soil criteria and thus require appropriate management in basins used for recreation.

   In low spots in the basins close to outfalls, lead concentrations in the surface soils (upper 1 to 2 inches) exceed the DHS criteria of 1,000 mg/kg for lead. For the two recreational basins in which spatial testing was done, the maximum lead concentration was between 1,600 and 2,300 mg/kg. Lead concentrations throughout most of the recreational basins are well under 1,000 mg/kg. The primary public health concern for lead is ingestion of soil. The opportunity for soil ingestion in the District's recreational basins is limited, since the recreational basins are entirely turfed with the exception of the baseball diamond infields in three basins. Also, the maximum concentration areas are not in the high exposure area of the infield. The impact of inhalation of dust particles containing lead was preliminarily assessed and this does not appear to be a problem based on comparison with the worker exposure criterion for lead.

4. Certain modifications to the District's current procedures are warranted to insure a future which continues to be free of adverse impacts.

   Although there are no identified health problems associated with current basin operation, the potential for future impacts does exist provided there is an absence of appropriate system management. Thus, the District should continue to manage and operate the basins in a manner that minimizes the risk to both groundwater quality and recreation. Certain suggested modifications to current practices can improve the degree of protection provided. Specific recommendations are developed in this next section.

RECOMMENDATIONS

Recommendations have been developed based on the conclusions just described. Our recommendations include several specific modifications to current operation of the retention/recharge system. There are some areas where a firm course of action cannot be recommended until further research or engineering is conducted.

Recommended Management Practices

A range of management practices were evaluated in Chapter 8. Specific recommendations are summarized in Table 9-1 and are briefly described below.

Table 9-1. Recommended Management Practices

1. Maintain the basic practice of retention and recharge of urban storm runoff subject to certain modifications.
2.[a] Provide low-flow basins for all recreational basins and evaluate low-flow basins for basins serving industrial areas. Periodically remove solids from the bottom of low-flow basins and from basins serving principally industrial areas.
3.[a] Remove the portion of the turf and upper soil layer from the recreational basins as necessary.
4.[a] Monitor soil from unturfed areas in recreational basins and remove as necessary.
5. Consider having industrial developments contain or pretreat runoff from portions of their site that may contain toxic material.
6. Have the District work together with other local agencies to be certain that water quality aspects are adequately considered in the review process for future industrial developments.
7. Develop a management plan to determine the best means of disposing of hazardous soil removed from the basins.
8. Continue the practice of recharging high quality imported surface water.
9. Implement a long-term monitoring program of basin soils and groundwater.

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[a] The need for soil removal should be based on further soils monitoring and contaminant buildup curves relative to public contact and drinking water standards.

1. The District should maintain its system of retention and recharge of urban storm runoff and make certain modifications to minimize health risks.

   The current system of retention and recharge is basically a very sound methodology for meeting its two goals: stormwater management and recharge of the groundwater supply. The fact that the system has operated successfully with proven water quality and recreational benefits for over 20 years is a credit to original design concept. The Fresno NURP project has enabled the operation to be scrutinized to assure that maximum protection to the groundwater supply and recreational uses of the basins is maintained in the future.

2. Low-flow basins should be provided for all recreational basins and for drainage areas where a significant amount of the contributing area will be developed for heavy industrial use.

   The low-flow basin concept that the District currently uses to contain summer runoff water from lawn sprinkling is an excellent means of containing the "first flush" of runoff and can thereby reduce the contaminant load that reaches the upper recreational basin, or the larger recharge basin in the industrial situation. In terms of existing basins serving industrial areas, the need for a low-flow basin should be assessed by either a detailed field inspection or a runoff monitoring program. The solids accumulations in the bottom of the low-flow basin should be periodically removed to prevent the leaching of this concentrated material into the deeper soils and ultimately to the groundwater. An alternative to a low-flow basin would be regular removal of existing basin soils.

3. A program to periodically remove the turf and upper soil layer from the recharge basins used for recreation should be initiated.

   At a minimum, the portions of the basin area that exceed the DHS soil criterion for lead should be periodically removed. The basin should then be returfed. Spatial sampling of the type conducted in this study for Basin F and Basin B/E should be performed to define the extent of soil removal requirements. Regular monitoring should be conducted to help define contaminant buildup curves. This program does not require urgent implementation, so it can be incorporated into the District's maintenance operations over the next few years. Basins with the highest contaminant levels should be dealt with first.

4. Unturfed areas at the recreational basins should be turfed over or alternatively the surface soil layer could be periodically removed.

   The unturfed portions of the recreational basins offer the greatest chance of public contact with the soil. Turfing or periodic soil removal, will minimize the potential problem.

5. Consideration should be given to having industrial developments contain or pretreat runoff from portions of their site that may contain toxic material.

   Industrial areas, such as the ones studied in this program, are the most significant potential source of urban runoff contaminants. Decisions to have upstream source control provided at existing industrial sites need to be developed on a case-by-case basis, since the types and magnitude of contaminants from industrial sites can vary widely.

6. The District should work together with other pertinent local agencies (e.g., planning and building departments) to be certain that water quality aspects are adequately considered in the review process for future industrial developments.

   Through this approach, provisions can be made during the design of industrial developments to control potential runoff contaminants at the source.

7. Develop a management plan to determine the best means of disposing of soil removed from the basins.

   Theoretically, soil that is removed from the basins that contains contaminants at concentrations exceeding DHS soil criteria will need to be hauled to a hazardous waste landfill. Disposal costs will be very expensive. Alternatives such as removing the soil before it reaches criteria levels or mixing contaminated soil with clean soil need to be evaluated.

8. Continue the practice of recharging high quality imported surface water.

   Recharge of high quality surface water has a beneficial effect on the regional groundwater quality. Although the imported water may gradually leach storm-produced pollutants from the soil, the large volumes of high quality water should adequately dilute contaminants to background levels. Also, periodic removal of surface soils will reduce the amount of contaminants that could be leached.

Areas Requiring Additional Work

The Fresno NURP project has met its primary objective of determining whether recharge of urban runoff is adversely affecting the groundwater supply. The secondary objective of assessing the impacts on recreational uses of the basins has also been addressed, although the recreational impacts are more difficult to define. The work conducted in this project has provided a basis for developing several recommendations. In the case of some of the recommendations, a detailed course of action cannot be implemented without further research or engineering. Also, some future monitoring is recommended in order to develop a continuing record of soil and groundwater quality and to assess the effectiveness of recommended control measures. Additional work requirements are listed below.

1. Long term annual soil and groundwater monitoring utilizing vacuum extractors at two or more of the existing test sites.

2. Long term soils and groundwater monitoring at a recharge basin serving an industrial area.

3. Continuing spatial surveys of the surface soils of the recreational basins to provide a basis for determining the timing and extent of soil removal.

4. Field inspection and/or runoff monitoring program of existing industrial sites (conducted cooperatively with the Central Valley Regional Water Quality Control Board).

5. Continuing assessment of downstream impacts of runoff water discharged into the San Joaquin River.

6. Evaluation of the engineering design standards of future recharge basins to consider pumpout arrangements, dual-compartment low-flow basins, bottom lining requirements, hydraulic controls for containment of chemical spills, etc.

APPENDIX A

REFERENCES

REFERENCES

1. California Department of Health Services. A summary of the Draft California Regulatory Criteria for Identification of Hazardous and Extremely Hazardous Wastes. October 1982.
2. County of Fresno. Interim Best Management Plan for Water Quality Fresno-Clovis Urban and Northeast Fresno County. June 1979.
3. Fresno Metropolitan Flood Control District. Work Plan for Determination of the Potential Adverse Environmental Impacts Associated with the Retention and Recharge of Urban Storm Runoff. October 1979.
4. Oltmann, Richard N. and Shulters, Michael V. Rainfall and Runoff Characteristics of Four Urban Land Use Catchments in Fresno, California, October 1981 - April 1983. U.S. Geological Survey. November 1983.
5. U.S. Department of Agriculture--Water Management Research Laboratory. Final Report for Fresno Nationwide Urban Runoff Program. September 1983.
6. U.S. Environmental Protection Agency. Final Report of the Nationwide Urban Runoff Program. September 1983.

APPENDIX B

CONSTITUENT LIST
AND ANALYTICAL DETECTION LIMITS

Table B-1. USGS Constituent List

	Runoff	Rainfall	Atmospheric dry deposition[a]	Street particulates[b]	Dry weather runoff
INORGANICS					
Field Measurements					
Specific conductance	X	X	X	–	3
pH	X	X	X	–	3
Major Ions					
Alkalinity (Bicarbonate and Carbonate	X	X	X	–	3
Sulfate, dissolved	X	X	X	–	3
Chloride, dissolved	X	X	X	–	3
Silica, dissolved	X	X	X	–	3
Calcium, dissolved	X	X	X	X	3
Magnesium, dissolved	X	X	X	X	3
Sodium, dissolved	X	X	X	X	3
Potassium, dissolved	X	X	X	X	3
Nutrients					
Nitrogen, Nitrite, dissolved (as N)	1	1	1	X	3
Nitrogen, Nitrite + Nitrate, dissolved (as N)	X	X	X	X	3
Phosphorus, dissolved (as P)	X	X	–	–	3
Phosphorus, total (as P)	X	–	X	X	3
Phosphorus, Orthophosphate, dissolved (as P)	X	X	–	–	3
Phosphorus, Orthophosphate, total (as P)	X	–	X	–	3
Nitrogen, Ammonia, dissolved, (as N)	X	X	X	X	3
Nitrogen, Ammonia + Organic, dissolved (as N)	X	X	X	–	3
Nitrogen, Ammonia + Organic, total (as N)	X	–	–	X	3
Metals					
Aluminum, dissolved and total	2	2	2	2	–
Arsenic, dissolved and total	X	2	2	X	3
Cadmium, dissolved and total	1	–	–	1	3
Chromium, dissolved and total	X	2	2	X	3
Copper, dissolved and total	X	2	2	X	3
Cyanide, dissolved and total	2	–	–	–	–
Iron, dissolved and total	X	2	2	X	3
Lead, dissolved and total	X	X	X	X	3
Manganese, dissolved and total	2	2	2	2	–
Mercury, dissolved and total	X	2	2	X	3
Nickel, dissolved and total	X	2	2	X	3
Zinc, dissolved and total	X	2	2	X	3
BIOLOGICAL					
Fecal coliform bacteria	X	–	–	–	3
OXYGEN DEMAND					
Five-day biochemical oxygen demand (B.O.D.)	X	–	–	–	–
Ultimate biochemical oxygen demand	1	–	–	–	–
Chemical Oxygen Demand (C.O.D.)	X	X	X	X	3
PHYSICAL PROPERTIES					
Turbidity	X	–	–	–	3
Solids, dissolved (180°C.)	X	–	–	–	3
Solids, total (105-110°C.)	–	–	X	–	–
Suspended sediment	X	–	–	–	3
Paricle size analysis	1	–	–	–	–

Table B-1. USGS Constituent List, continued

	Runoff	Rainfall	Atmospheric dry deposition[a]	Street particulates[b]	Dry weather runoff
ORGANICS					
Gross Measures					
Dissolved organic carbon	X	X	X	-	3
Suspended organic carbon	X	-	-	-	3
Oil and grease, total	X	-	-	-	-
Polychlorinated biphenyls, total	X	X	2	X	3
Polychlorinated napthalenes, total	X	X	2	X	3
Dibromochloropropane (DBCP)	1	-	-	-	-
Phenols, total recoverable	2	2	-	-	-
Volatile Organics					
Benzene, total recoverable	2	-	-	-	-
Chlorobenzene, total recoverable	2	-	-	-	-
Ethylbenzene, total recoverable	2	-	-	-	-
Organochlorine Compounds					
Aldrin, total	X	X	2	X	3
Chlordane, total	X	X	2	X	3
DDD, total	X	X	2	X	3
DDE, total	X	X	2	X	3
DDT, total	X	X	2	X	3
Dieldrin, total	X	X	2	X	3
Endosulfan, total	X	X	2	X	3
Endrin, total	X	X	2	X	3
Heptachlor, total	X	X	2	X	3
Heptachlor epoxide, total	X	X	2	X	3
Lindane, total	X	X	2	X	3
Methoxychlor, total	X	X	2	X	3
Mirex, total	X	X	2	X	3
Perthane, total	X	X	2	X	3
Toxaphene, total	X	X	2	X	3
Organophosphorus Compounds					
Diazinon, total	X	X	2	X	3
Ethion, total	X	X	2	X	3
Malathion, total	X	X	2	X	3
Methyl parathion, total	X	X	2	X	3
Methyl trithion, total	X	X	2	X	3
Parathion, total	X	X	2	X	3
Trithion, total	X	X	2	X	3
Carbamate Insecticides					
Methomyl, total	1	1	-	-	-
Propham, total	1	1	-	-	-
Sevin, total	1	1	-	-	-
Chlorophenoxy Acid Herbicides					
2,4-D, total	X	X	2	X	3
2,4-DP, total	X	X	2	-	3
2,4,5-T, total	X	X	2	-	3
Silvex, total	X	X	2	-	3

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[a] Dry deposition material is washed from collection bucket with deionized water and then analyzed as a water sample.

[b] All constituents are total recoverable from a dry sample, therefore, disregard "dissolved" notation after constituent name.

Chart Symbols

X - Analyzed for during both rain seasons.
1 - Analyzed for during 1981-82 rain season only.
2 - Analyzed for during 1982-83 rain season only.
3 - Analyzed for September 3, 1982 samples.

Table B-2. Detection Limits for Various Organic Constituents in Water Samples (USGS Laboratory)

Constituent	Detection limit,[a] ug/l
Aldrin	0.01
Chlordane	0.1
Diazinon	0.01
Dieldrin	0.01
DDD	0.01
DDE	0.01
DDT	0.01
Endosulfan	0.01
Endrin	0.01
Ethion	0.01
Heptachlor	0.01
Heptachlor epoxide	0.01
Lindane	0.01
Malathion	0.01
Methomyl	0.5-2
Methoxychlor	0.01
Methyl parathion	0.01
Methyl trithion	0.01
Mirex	0.01
Parathion	0.01
Perthane	0.1
Phenol	2
Polychlorinated naphthalenes	0.1
Propham	0.5-2
PCB	0.1
Sevin	0.5-2
Silvex	0.01
Toxaphene	1
Trithion	0.01
2,4-D	0.01
2,4-DP	0.01
2,4,5-T	0.01

[a] Detection limit varies with the size of available water sample.

Table B-3. Detection Limits for Various Organic Constituents in Soils and Groundwater Samples (Brown and Caldwell Laboratory)

Constituent	Detection limit	
	Water,[a] ug/l	Soil, mg/kg
Aldrin	0.05 - 0.22	0.01
Chlordane	0.11 - 1.4	0.03
DDT (mixed isomers)	0.1 - 0.50	0.03
DDE (mixed isomers)	0.05 - 0.22	0.01
DDD (mixed isomers)	0.05 - 0.22	0.01
Endosulfan I and II	0.05 - 0.22	0.01
Endosulfan sulfate	0.02 - 0.50	0.03
Gamma BHC (lindane)	0.05 - 0.22	0.01
Methoxychlor	0.2 - 1.0	0.07
2,4-D	0.25 - 2.2	0.02
Diazinon	0.02 - 0.5	0.02
Malathion	0.03 - 1.0	0.04
Parathion	0.02 - 1.0	0.04
Methyl parathion	0.03 - 1.0	0.04
Semivolatiles[b]		
Hexachlorocyclopentadiene	200	0.05
2,4-dinitrophenol	200	0.05
4-chlorophenylphenyl ether	400	0.20
All others	10 - 25	0.04
Purgeables[c]	-	0.001

[a] Detection limit varies with the size of available water sample.

[b] Complete list shown in Table B-4.

[c] Complete list shown in Table B-5.

Table B-4

SEMIVOLATILE PRIORITY POLLUTANTS - EPA METHOD 625

Group I: Base Neutrals	Characteristic Ions
D_8-Naphthalene (I.S.)	136
N-Nitrosodimethylamine	42, 44, 74
bis-(2-chloroethyl)ether	63, 93, 95
1,3-Dichlorobenzene	113, 146, 148
1,4-Dichlorobenzene	113, 146, 148
1,2-Dichlorobenzene	113, 146, 148
bis-(2-chloroisopropyl)ether	45, 77, 79, 121
Hexachloroethane	117, 199, 201
n-Nitroso-di-n-propylamine	42, 70, 101, 130
Nitrobenzene	65, 77, 123
Isophorone	82, 95, 138
bis(2-chloroethoxy)methane	93, 95, 123
1,2,4-Trichlorobenzene	145, 180, 182
Naphthalene	127, 128, 129
Hexachlorobutadiene	223, 225, 227
Hexachlorocyclopentadiene	235, 237, 239, 272
2-Chloronaphthalene	127, 162, 164
Acenaphthylene	151, 152, 153
Dimethylphthalate	163, 164, 194
2,6-Dinitrotoluene	63, 165, 121
D_{10}-Anthracene (I.S.)	80, 94, 188
Acenaphthene	152, 153, 154
2,4-Dinitroltoluene	89, 163, 165
Fluorene	165, 166, 167
Diethylphthalate	149, 150, 177
4-Chlorophenylphenyl ether	141, 204, 206
n-Nitrosodiphenylamine	167, 168, 169
1,2-Diphenylhydrazine	77, 93, 105
4-Bromophenoxybenzene	141, 248, 250
Hexachlorobenzene	142. 249, 284

Group I (continued)	Characteristic Ions
Butylbenzylphthalate	91, 149
Benzo(a)anthracene	226, 228, 229
3,3-Dichlorobenzidine	126, 252, 254
Chrysene	226, 228, 229
bis(2-ethylhexyl)phthalate	149, 167, 279
di-n-octyl phthalate	149
Benzo(b)fluoranthene	125, 252, 253
Benzo(k)fluoranthene	125, 252, 253
Benzo(a)pyrene	125, 252, 253
Indeno(1,2,3-cd)pyrene	138, 276, 277
Dibenzo(ah)anthracene	139, 278, 279
Benzo(ghi)perylene	138, 276, 277
Benzidine	92, 184, 185
Pyrene	100, 101, 202
Fluoranthene	100, 101, 202
di-n-butylphthalate	104, 149, 150
Anthracene	176, 178, 179
Phenanthrene	176, 178, 179
Group II: Acids	
2-Chlorophenol	64, 128, 130
2-Nitrophenol	65, 109, 139
Phenol	65, 66, 94
2,4-Dimethylphenol	107, 121, 122
2,4-Dichlorophenol	98, 162, 164
2,4,6-Trichlorophenol	196, 198, 200
4-Chloro-3-methylphenol	107, 142, 144
2,4-Dinitrophenol	63, 154, 184
2-Methyl-4,6-dinitrophenol	77, 182, 198
Pentachlorophenol	264, 266, 268
4-Nitrophenol	65, 109, 139

I.S. = Internal Standard.

Table B-5

PURGEABLE PRIORITY POLLUTANTS - EPA METHOD 624

Compound	Characteristic Ions
Bromochloromethane (I.S.)	49, 51, 130, 128
Chloromethane	50, 52
Dichlorodifluoromethane	85, 87
Bromomethane	94, 96
Vinyl chloride	62, 64
Chloroethane	64, 66
Methylene chloride	49, 51, 84, 86
Trichlorofluoromethane	101, 103
1,1-Dichloroethylene	61, 96, 98
1,1-Dichloroethane	63, 65, 83
trans-1,2-Dichloroethylene	61, 96, 98
Chloroform	83, 85
1,2-Dichloroethane	62, 64, 98, 100
1,1,1-Trichloroethane	97, 99, 117, 119
Carbon tetrachloride	117, 119, 121
Bromodichloromethane	83, 85, 127, 129
1,4-Dichlorobutane (I.S.)	55, 90, 92
1,2-Dichloropropane	63, 65, 112, 114
trans-1,3-Dichloropropene	75, 77
Trichloroethylene	95, 97, 130, 132
Benzene	78
cis-1,3-Dichloropropene	75, 77
Dibromochloromethane	129, 127, 208, 206
Bromoform	171,173,175,250,252,254,256
1,1,2,2-Tetrachloroethylene	129, 131, 164, 166
1,12,2-Tetrachloroethane	83, 85, 131, 133, 166, 168
Toluene	91, 92
Chlorobenzene	112, 114
Ethylbenzene	91, 106
2-Bromo-1-chloropropane (I.S.)	77, 79, 156
2-Chloroethylvinyl ether	63, 65, 106
Xylene	91, 106
Xylene	91, 106
n-Butyl acetate*	56, 73
Bromochloromethane (I.S.)	49, 130, 128, 51
Acrolein	55, 56
Acrylonitrile	50, 51, 32, 53
Acetone*	58
Acetonitrile*	41, 42, 38, 39, 30
Isopropanol*	45, 43, 59
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113)*	151
Methyl ethyl ketone*	43, 57, 72
Ethyl acetate*	43, 88, 70, 73, 61
1,1,2-Trichloroethane	83, 85, 97, 99, 132, 134

*Not a priority pollutant or an internal standard. Included due to interest by some California regulatory authorities.
The underlined characteristic ions are used for quantitation.
I.S. = Internal Standard

APPENDIX C

SUPPORTING DOCUMENTS

SUPPORTING DOCUMENTS

A very large data base was developed as part of the Fresno NURP project. These data were compiled in the following supporting documents:

Quarterly Report No. 6, May 18, 1982

Quarterly Report No. 7, August 20, 1982

Quarterly Report No. 8, November 22, 1982

Quarterly Report No. 9, March 8, 1983

Quarterly Report No. 10, May 31, 1983

Quarterly Report No. 11, August 9, 1983

First Annual Report, October 20, 1982

Second Annual Report, September 20, 1983

U.S. Geological Survey draft NURP report entitled "Rainfall and Runooff Characteristics of Four Urban Land Use Catchments in Fresno, California, October 1981 to April 1983", dated November 1983 (the final report is in preparation).

U.S. Department of Agriculture, Water Management Research Laboratory Final NURP Report and Appendices, September 1983.

These reports are all available through the Fresno Metropolitan Flood Control District, Rowell Building, Suite 300, 2100 Tulare Street, Fresno, California, 93721. The USGS and USDA final reports are also available directly from those agencies: USGS, 2800 Cottage Way, Sacramento, California, 95825; USDA, 5544 East Air Terminal Drive, Fresno, California, 93727.